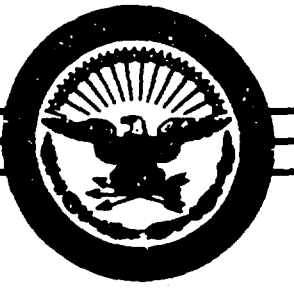

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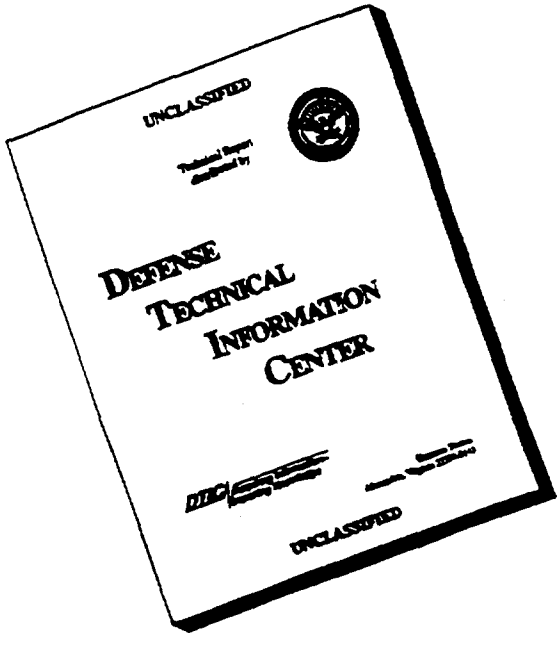

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REPORT
NO. 1269

CRITERIA FOR INCAPACITATING SOLDIERS WITH FRAGMENTS AND FLECHETTES (U)

By William Kokinakis
Joseph Sperrazza

JANUARY 1965

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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BALLISTIC RESEARCH LABORATORIES

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CRITERIA FOR INCAPACITATING SOLDIERS WITH FRAGMENTS AND FLECHETTES (U)

William Kokinakis
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RDT&E Project No. 1P025601A27

ABERDEEN PROVING GROUND, MARYLAND

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BALLISTIC RESEARCH LABORATORIES

REPORT NO. 1269

WKokinakis/JSperrazza/mec
Aberdeen Proving Ground, Md.
January 1965

CRITERIA FOR INCAPACITATING SOLDIERS WITH FRAGMENTS AND FLECHETTES (U)

(CONFIDENTIAL) ABSTRACT

Presented are estimates of the conditional probabilities, P_{hk} that single, random hits with a standard series of homologously shaped, steel flechettes, which tumble within a soldier, will incapacitate the soldier. The functional dependence of P_{hk} on the weight, m of the flechette and its initial striking velocity, v_o is given by

$$P_{hk} = 1 - e^{-a(mv_o^{3/2}-b)^n}$$

where e is the base of the natural logarithm and a, b and n are parameters whose values are determined from the tactical situation and time at which the incapacitation is to ensue. The analysis was based on experimental data produced by the Biophysics Division, Medical Directorate, Chemical Research and Development Laboratories (CRDL), Edgewood Arsenal.

The Edgewood experiments demonstrate that within "ballistic" simulants of the human anatomy; i.e., gelatin or goats, relatively quick tumbling occurs with the standard series of flechettes for striking velocities greater than 3000 fps. It is suggested that the weight of the flechette should not exceed about 13 grains else the tumbling will occur too late after entrance and that only a small portion of the flechette's energy will be deposited within the target.

Also presented are estimates of the conditional probability that single, random hits with chunky (spheres or cubes), steel fragments will incapacitate a soldier. Although these latter criteria appear in other Ballistic Research Laboratories (BRL) publications, they are included for purposes of consolidation.

(UNCLASSIFIED) TABLE OF CONTENTS

A NOTE ON CLASSIFICATION

The plan of the experiments, including the types of targets used, is CONFIDENTIAL. The functional dependence of P_{hk} or the variables m and v_o and unspecified numerical values of the parameters a, b, n is classified CONFIDENTIAL; on the other hand, when numerical values are given for a, b, n the relation is classified SECRET.

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(CONFIDENTIAL) INTRODUCTION

The U. S. Army program on wound ballistics was started about 1950 as a cooperative effort among three, then Army Technical Services: Ordnance Corps, Chemical Corps and Medical Services. Its main purpose was, and still is, to develop casualty criteria for infantry soldiers struck by penetrating missiles such as unstabilized fragments, bullets and arrow-like missiles termed flechettes. Presently the program is continuing under auspices of the Army Materiel Command, with the cooperation of the Medical Services.

The study involves two distinct phases: (1) the conduct of appropriate experiments and the assessment of hypothetical wounds in terms of incapacitation -- this phase is carried out by the Biophysics Division, CRDL, Edgewood Arsenal, and (2) the formulation of criteria for incapacitation in terms of missile parameters -- this phase is carried out by the BRL. The reader is referred to BRL Report No. 996[1*], dated October 1956 for a general description of the work and for the formulation of the earlier criteria that were developed for chunky steel fragments**. Those criteria were based on experiments with 0.85-grain spheres and 2.0- and 16.0-grain cubes.

In BRL Report No. 996, the dependence of P_{hk} on the weight (m) and striking velocity (v_o) for steel fragments was found to be as follows:

$$P_{hk} = 1 - e^{-a(mv_o^{3/2}-b)^n}$$

where m is weight of fragment, v_o is the striking velocity, e the base of the natural logarithm and a, b and n are parameters whose values

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* *Superscript numbers denote references found on page 28.*

** *The steel fragments are presumed to be generic to those generated by the detonation of high explosive shell.*

depend on time after wounding and tactical role*. Reported were values of a, b and n associated with each of four tactical roles and seven post-wounding times. However, of the total of 28 combinations, four had been selected as being representative of all of them:

Case	Standard	Representative of
1	Defense ≤ 30 Seconds	Defense ≤ 30 Seconds
2	Assault ≤ 30 Seconds	Assault ≤ 30 Seconds
		Defense ≤ 5 Minutes
3	Assault ≤ 5 Minutes	Assault ≤ 5 Minutes
		Defense ≤ 30 Minutes
		Defense ≤ 12 Hours
4	Supply ≤ 12 Hours	Supply ≤ 12 Hours
		Supply ≤ 24 Hours
		Supply ≤ 5 Days
		Reserve ≤ 30 Minutes
		Reserve ≤ 12 Hours
		Reserve ≤ 24 Hours

The effectiveness of weapons of the artillery type are evaluated, in general, using the criterion for Case 3 and weapons of the personal type (rifles, hand grenades, etc.) are evaluated using the criterion for Case 1.

Data obtained later with a 225-grain steel cube were in accord with the general rules proposed in BRL Report No. 996.

Subsequent reevaluations of all previous medical assessments of the incapacitating potential of the steel fragments[2] resulted in revised criteria which were published in BRL Technical Note No. 1297[3]. However, the main purpose of that note was to suggest tentative criteria of the incapacitating potential of an homologous series of steel flechettes pending the completion of experiments with the homologous series[4,5,6].

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* *The four significant tactical roles considered in this study are described in Appendix A.*

The provisional estimates of the wounding potential of the flechettes were restricted to those that remained stable in the simulants of human targets (gelatin or goats); it was observed that when the striking velocity was less than about 3000 fps, tumbling within target did not occur whereas if the striking velocity exceeded 3000 fps, the flechette tumbled relatively quickly and deposited more energy in the target than did the more stable flechette, and therefore produced grosser wounds.

It is the purpose of the present study to report the casualty criteria for tumbling flechettes and to include, under one cover, the latest criteria for fragments and non-tumbling flechettes. (This publication supersedes and/or compliments casualty criteria previously published in the following BRL Reports: Report No. 996[1], Technical Note Nos. 1297[3], 1235[7], 1437[8], and 1486[10], and Memorandum No. 1420[9].) The criteria pertain to single, random hits averaged over the whole body or averaged over the major separate parts of the anatomy such as the head and neck, thorax, abdomen, pelvis, and arms and legs. The latter breakdown should be useful to designers of body armor, helmets, and other protective devices.

(CONFIDENTIAL) EXPERIMENTAL PROCEDURE

For each combination of missile and striking velocity the procedure for establishing the size (depth and lateral extent) of a hypothetical wound tract in a soldier first involves firing the missile into different types of anatomical components of goats. Measurements are made of the retardation in velocity of the missile while penetrating different thicknesses of the components*. Supplementary experiments include the determinations of physical damage to especially critical components. In general, the tissue models are obtained from Angora goats. However, human skulls and limbs are occasionally used for the experiments. Firings are also made into whole, live goats and complete descriptions of each wound tract are obtained by autopsy. All these data serve as inputs to

* *To account for protection that could be offered by clothing, body armor, etc., retardation firings are also carried out with such materials.*

medical assessors who then estimate physiological effects in soldiers subjected to the many hypothetical wounds that could arise from random strikes. It is the purpose of the remainder of this section to describe briefly the assessing technique.

To aid in the identification of the various tissue and organs that lie in the many different paths of a missile's trajectory (wound tract), and to combine these structures with degree of traumatic damage a "bookkeeping" procedure was set up, as typified by the example illustrated in Table I. The combinations of anatomical components struck and the degree of damage are called "wound classes".

TABLE I

(UNCLASSIFIED) Typical Wound Classes

Symbol	Description
B_2	SKULL; severe fragmentation or depressed fracture
$B_{a7}V_2$	BONE; with concurrent cardiovascular wound
$B_{L1}V_1$	BONE; with concurrent cardiovascular wound
H_1	HAND; any wound at this velocity
K_2	URETER, URETHRA and URINARY BLADDER; puncture wound with leakage
N_aV_2	NERVE; with concurrent cardiovascular damage
P_7	LUNG; puncture with small blood loss

The reader is referred to the referenced CRDL Reports 4, 5, and 6 for a complete description of the procedure.

In Table I, the subscript 2 of B_2 denotes severity of the bone wound. The subscript L of $B_{L1}V_1$ denotes bone damage affecting the legs and V identifies it as a combination wound involving vascular damage as well. The subscript 1 of V_1 indicates the degree of incapacitation and is based on vascular size, location of vessel and wound size. And so on until there are described all the possible wound classes that a specific missile can produce. The number of wound classes varies with the type, weight, and striking velocity of missile.

The next step in the procedure is to relate wound classes with the decrement in task performance of the soldier. Because of the intimate dependence of performance on the behavior of the limbs, incapacitation arbitrarily was related to behavior of the limbs. Table II lists a total of 16 disability (or functional groups) which consider different combinations of limb deficits that can occur from practical considerations. The deficit either could be one in which loss of fine muscular coordination of a limb occurs or one in which total loss of the limb occurs. A limb need not necessarily be hit to become disabled. For example, a hit on certain parts of the spinal cord could render all extremities inoperable.

Of crucial significance to the study are the judgments made by the medical assessors on the relationships between behavior of the limbs and the ability of the wounded "enemy" soldier to carry out his assigned task. Table III represents the best estimates of these relationships and are based on a consensus of opinion of medical assessors and of combat personnel. Each discrete level of disability refers to, "on the average", the decrease in effectiveness of the enemy soldier. Some of the readers of this report might wish to defer reading the next several pages and turn to subsequent paragraphs which define the term P_{hk} (page 16).

Only six discrete post-wounding times ranging from one-half a minute to five days are considered in the assessments. Generally, as post-time wounding increases, the deleterious effects of a wound accumulate and the wound is assigned to a functional group associated with a higher level of incapacitation.

Some examples of the change in functional group with time are given in Table V. Table V is illustrative only and applies to a 7.2-grain steel flechette striking the bare skin of the "enemy" soldier at a velocity of 2000 fps. There are very few exceptions to the cumulative effects of the wound. For instance, let us examine wound class $B_{a7}V_2$. After 24 hours, this wound class falls into Functional Group XIII which rates 100% incapacitation for all tactical roles; but at five days this wound class falls into Functional Group VIII, which rates 75% incapacitation for three of the four tactical roles. The significance here is that the wound, if left unattended would start to heal after 24 hours.

TABLE II

(UNCLASSIFIED) The Relation Between Functional Group and Behavior of Each Extremeity

Functional Group	Arms*	Legs*
I	N,N	N,N
II	N,N	N,F
III	N,N	F,F
IV	N,N	N,T
V	N,N	T,T
VI	N,F	N,N
VII	F,F	N,N
VIII	N,T	N,N
IX	T,T	N,N
X	F,F	F,F
XI	F,F	F,T
XII	F,F	T,T
XIII	F,T	F,F
XIV	T,T	T,T
XV	N,N	F,T
XVI	N,F	F,F

Code: N No effect on extremity
F Loss of fine muscular coordination (weakness) of extremity
T Total loss of extremity function
* No attempt is made to differentiate between the right and left limbs

TABLE III

(CONFIDENTIAL) Percent Disability Vs. Functional Group for Four Tactical Situations (U)

Each* Arm	Each* Leg	Functional Groups	Percent Disability Assault	Defense	Reserve	Supply
N,N	N,N	I	0	0	0	0
N,N	N,F	II	50	25	75	25
N,N	F,F	III	75	25	100	50
N,N	N,T	IV	100	50	100	100
N,N	T,T	V	100	50	100	100
N,F	N,N	VI	50	25	75	25
F,F	N,N	VII	75	50	100	50
N,T	N,N	VIII	75	75	100	75
T,T	N,N	IX	100	100	100	100
F,F	F,F	X	75	75	100	75
F,F	F,T	XI	100	75	100	100
F,F	T,T	XII	100	75	100	100
F,T	F,F	XIII	100	100	100	100
T,T	T,T	XIV	100	100	100	100
N,N	F,T	XV	100	50	100	100
N,F	F,F	XVI	75	50	100	75

Codes: N No effect
F Loss of fine muscular coordination
T Total loss of extremity function
* No attempt is made to differentiate between the right and left limbs.

Table IV is a rearrangement of Table III.

TABLE IV

(CONFIDENTIAL) Functional Groups Vs. Percent Disability for Four Tactical Situations (U)

Percent Disability	Functional Group			
	Assault	Defense	Reserve	Supply
0	I	I	I	I
25	-	II,III,VI	-	II,VI
50	II,VI	IV,V,VII XV,XVI	-	III, VII
75	III,VII,VIII, X,XVI	VIII,X,XI, XII	II,VI	VIII, X,XVI
100	IV,V,IX,XI, XII,XIII,XIV, XV	IX,XIII, XIV	III,IV,V, VII,VIII, IX,X,XI, XII,XIII, XIV,XV,XVI	IV,V, IX,XI, XII, XIII, XIV,XV

TABLE V

(C) Effect of Post-Wounding Time on Assignment of Functional Group (U)

Wound Class	Description	Functional Group*					
		30 sec.	5 min.	30 min.	12 hr.	24 hr.	5 days
B_2	SKULL; severe fragmentation, or depressed fracture	XIV	XIV	XIV	XIV	XIV	XIV
$B_{a7}V_2$	BONE; with concurrent cardiovascular wound	VI	X	XIV	XIII	XIII	VIII
$B_{L1}V_1$	BONE; with concurrent cardiovascular damage	IV	XV	XI	XI	XI	XI
H_1	HAND; any wound at this velocity	VI	VI	VI	VI	VI	VI
K_2	URETER, URETHRA, AND URINARY BLADDER; puncture wound with leakage	I	I	I	X	XIV	XIV
N_aV_2	NERVE; with concurrent cardiovascular damage	VI	X	XIV	X	X	VI
P_7	LUNG; puncture with small blood loss	I	III	X	X	X	XIV

* *One might wish to cross-reference Table V with Tables III or IV to determine the relation between wound class and percent disability associated with tactical role and post-wounding time.*

The wound classes describe the degree of traumatic damage which occurs in the anatomical structures. To determine specific portions of a soldier's anatomy which are vulnerable to the missile's penetration; the anatomical cross-sectional charts in the text[11] by Eycleshymer and Shoemaker were chosen as standard. These charts, which consider an "average man" to be 69 inches in height and 155 pounds in weight, "slice" our theoretical soldier into 108 horizontal cross sections*. Section 1, starting with the top of the head, through Section 18, are 1.2 cm. thick; the remaining sections are 2.6 cm. thick. The process of horizontal scanning, for six equiangular rotations starting with the anterior as zero degrees, can result in as many as 100,000 trajectories for each missile at each velocity. Until recently, personnel of the Biophysics Division accomplished the task by hand; the time required to project one missile at three velocities was roughly two months. A computer program has been written by BRL[12], and the BRLESC Computer can now perform the same task in one hour.

The projections are made only for horizontal trajectories through an erect soldier. The soldier is assumed to be standing in the standard anatomical position on the balls of his feet with his arms at his side and palms facing forward. It is further assumed that no part of his body shields any other. The trunk is projected with the extremities removed, and the arms and legs are projected as though removed from the trunk. However, the BRL presently is programming the anatomy so that trajectories other than normal can be evaluated. Hopefully, this project will be completed within the next few months.

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* *It is hoped that anthropological differences that exist among diverse ethnic groups will not affect materially the adequacy of the criteria (P_{hk}) that finally are derived. For example, we are assuming tacitly that ratios of vulnerable areas to presented areas are independent of size of the individual. Actually, we recognize that smaller statured individuals should be more susceptible to wounding because they enjoy less protective tissue such as skin, muscle, etc. But when computing the expected number of casualties that could be produced by a weapon, one must account for the probability that the enemy soldier will be struck. But, the smaller the soldier, the lower the hit probability. Hence an increased P_{hk} is compensated to some extent by a decreased probability of being hit. A study of this kind, at the present time, is unwarranted.*

In the projection process, the entire body is surveyed and divided into six major anatomical subdivisions; head and neck, thorax, abdomen, pelvis, 2 arms and 2 legs. The arms are further subdivided into upper arms and elbows, lower arms, wrists and hands and the legs are subdivided into upper legs and knees, lower legs, ankles and feet. This subdivision allows incapacitation data to be obtained for major subdivisions, as well as for an average for the entire body.

The Biophysics Division of CRDL present their results in the form of tables as illustrated by Tables VI and VII for a 7.2-grain steel flechette striking the bare torso at a velocity of 2000 fps. The enemy soldier is considered to be in an assault role. Table VI pertains to the post-wounding time of five minutes and is restricted to the thorax. It lists values of the areas* of critical components vulnerable to the attack by the given fragment at the residual velocity of the fragment after penetrating through any protective anatomical components. The cross sections 19-27 refer to Eycleshymer and Shoemaker cross-sectional anatomy chart numbers, 19-27. Table VII is restricted to the thorax, abdomen, and lower legs and lists percent incapacitations for six post-wounding times. Data such as in Table VII can be summarized to yield average incapacitations for the entire body.

Table VIII presents such a summary for the whole body. Listed are the percent incapacitation, disability groups, percent of body area subjected to incapacitation, and the time after wounding. Again the 7.2-grain steel flechette with a striking velocity of 2000 fps is illustrated for the assault role.

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* *Averaged over six different directions. It is to be pointed out that for each direction sufficient trajectories are introduced into each slice so that complete overlapping exists between adjacent trajectories. The first direction is for strikes perpendicular to the anterior; each successive direction is at multiple integers of 60°.*

TABLE VI

(UNCL) Mean Vulnerable Areas (cm^2) of Some Critical Components of the Thorax

Anatomical Cross Sections: 19-27

Wound Class (Critical Component)	Vulnerable Area
Ba_7	26.8
Bv_7	1.7
Na_1	4.8
NL_2	1.3
P_7	134.0
V_2	21.1
V_4	184.5

TABLE VII

(SECRET) Percent Incapacitation for Selected Anatomical Regions with a 7.2-Grain Steel Flechette at 2000 fps (U)

Tactical Role: Assault

Subdivision % Total Body Area	% Incapacitation	Percent of Total Body Area that is Subject to Incapacitation					
		30 Sec.	5 Min.	30 Min.	12 Hr.	24 Hr.	5 Days
Thorax 12.8	0	9.9	3.1	2.6	2.9	3.0	3.4
	25	-	-	-	-	-	-
	50	2.3	2.3	2.3	1.8	1.8	1.8
	75	0.1	6.9	3.5	4.1	3.5	3.1
	100	0.5	0.5	4.4	4.0	4.5	4.5
Abdomen 10.5	0	10.1	7.2	3.8	2.0	2.0	5.7
	25	-	-	-	-	-	-
	50	-	-	-	-	-	-
	75	-	2.9	4.7	3.3	5.8	0.3
	100	0.3	0.3	2.0	5.2	2.7	4.4
Lower Legs 10.2	0	4.5	4.1	3.4	4.1	4.3	4.5
	25	-	-	-	-	-	-
	50	0.2	<0.1	<0.1	<0.1	<0.1	0.2
	75	-	0.6	1.0	0.6	0.3	-
	100	5.5	5.6	5.8	5.5	5.5	5.5

TABLE VIII

(SECRET) Percent Incapacitation for the Whole Body with a 7.2-Grain Steel Flechette at 2000 fps (U)

Tactical Role: Assault

% Incapacitation	Disability Group	Percent of Total Body Area that is Subject to Incapacitation					
		30 Sec.	5 Min.	30 Min.	12 Hr.	24 Hrs.	5 Days
None - 0	I	57.9	41.4	34.6	33.9	35.6	40.6
Mild - 25	-	-	-	-	-	-	-
Moderate - 50	II,VI	24.8	21.2	21.2	9.9	10.0	10.3
Severe - 75	III,VII, VIII,X,XVI	1.3	21.0	17.4	18.7	16.8	8.1
Total - 100	IV,V,IX,XI XII,XIII, XIV,XV	16.0	16.3	26.8	37.5	37.6	41.0

The numbers in the table represent the percentage of the average projected body area (averaged over 6 directions) which, if hit, would result in a particular percentage level of incapacitation. Thus, the conditional probability, P_{hk}, that a random hit results in an incapacitation is taken to be:

$$P_{hk} = \frac{\Sigma(P_i A_i)}{\Sigma A_i}$$

P_i is the average incapacitation associated with the hits on a subdivision whose average subtended area is A_i. ΣA_i is the total presented area of the body. Thus, for the post-time wounding of 5 minutes we estimate from Table VIII the following value for P_{hk}:

$$P_{hk} = (0 \times 0.414) + (.25 \times 0) + (.50 \times 0.212) + (.75 \times 0.210) + (1 \times 0.163)$$

$$P_{hk} = 0.43.$$

The term "probability of incapacitation" is a misnomer here. Actually, what is derived is an estimate of an average level of incapacitation that could be imposed on a soldier as a result of a random hit with a particular missile at a specific striking velocity. If we were dealing with a dichotomy, that is, if a hit either incapacitated (P_i = 100%) or did not

incapacitate (P_i = 0%), then P_{hk} would represent the probability of incapacitation. For the moment let us admit the concept of a dichotomy. Then, if an assessor evaluated a hit at an intermediate level of incapacitation, say P_i = 25%, it would mean that he was uncertain to the extent of 25% that the hit would result in no incapacitation; or conversely, he was uncertain to the extent of 75% that the hit would result in full incapacitation.

But in our case this is not what the assessor means when he assesses a hit at an intermediate level of incapacitation. For example, if he associates with a specific wound the level P_i = 25%, he means that the soldier would not be able to perform 25% of his duties.

We must realize that the assessments are subjective and depend on clinical and field experience of the medical officer(s). Because of potential errors of subjectivity a conservative approach was adopted in the procedure for making assessments. Along each hypothetical wound track only that anatomical component that would constitute the highest incapacitation is considered in the establishment of the wound class; either individual or synergistic effects of all other components in the tract are not included.

When weapons systems analysts or designers evaluate the lethality of a fragmenting shell the usual thing to do is to estimate the number of casualties that would be caused under a specific set of conditions. Briefly, the expected number of casualties can be found from the following expression:

$$E(C) = \int\int \sigma(x,y)\, P_k\,(x,y)\, dxdy$$

where $\sigma(x,y)$ is the areal density of troops at a specific point (x,y) on the ground, and $P_k(x,y)$ is the probability that a soldier located in the elemental area dxdy will be incapacitated. $P_k(x,y)$ takes into account the number of hits on the soldier and the probability that each hit will cause an incapacitation. Neglecting synergistic effect of multiple

wounds and assuming that P_{hk} is relatively small for each hit, then P_k can be computed from the binomial expansion.

$$P_k = 1 - (1 - P_{hk_1}) (1 - P_{hk_2}) \cdots (1 - P_{hk_i}).$$

The reader is referred to BRL Technical Note No. 1511 for a more detailed description of the formulation of E(C).

(CONFIDENTIAL) RESULTS AND DISCUSSION

Tables IX and X summarize some of the physical characteristics of the steel fragments and the homologous series of steel flechettes used for the experiments.

TABLE IX

(UNCLASSIFIED) Characteristics of Fragments

Missile	Weight grams	Dimension cm.	Presented Area* sq. cm.
**Sphere, 0.85 gr.	0.055	0.236 (Diameter)	0.044
***Cube, 2.1 gr.	0.136	0.282 x 0.282 x 0.216	0.101
***Cube, 16.0 gr.	1.06	0.505 x 0.513 x 0.518	0.393
***Cube, 225 gr.	14.7	1.22 x 1.22 x 1.27	2.30

* *For Cubes: Presented Area* $= \frac{\textit{Surface Area}}{4}$

** *Commercially available ball bearings*

*** *ASTM 1020 Steel -- note that the "cubes" actually were rectangular parallelepipeds.*

TABLE X

(UNCLASSIFIED) Characteristics of WP Flechettes*

Missile	Weight grams	Length cm.	Shaft Diameter cm.	Fins No.	Fins Span cm.	Fins Thickness cm.	Frontal** Presented Area sq. cm.
1.72 gr.	0.112	1.71	0.114	4	0.287	0.018	0.0164
7.2 gr.	0.464	2.75	0.180	4	0.450	0.030	0.0416
15.2 gr.	0.982	3.40	0.236	4	0.594	0.043	0.0745

Estimates of the probability of incapacitation (P_{hk}) were made at three striking velocities for each of the four fragments and three flechettes. The 0.85-grain sphere, the 2.1-grain cube and 16.0-grain cube were evaluated at nominal striking velocities of 1000, 3000, and 5000 fps; those for the 225-grain cube were 500, 1000, and 2500 fps. The three flechettes were evaluated at nominal striking velocities of 500, 2000, and 4000 fps.

A relationship which, on the average, yielded a good fit to the experimental data for the whole body was:

$$P_{hk} = 1 - e^{-a(mv^{3/2}-b)^n}$$

where different values of the parameters a, b, n were associated with each different combination of tactical role and post-wounding time. Further, we a priori assumed that the same relationship held for each of the major body sections. Thus, if P_{hk_j} is this conditional probability for the jth part, and r_j is the relative presented area of the jth part, then

$$P_{hk} = \Sigma(r_j P_{hk_j}) .$$

* *Made by Whirlpool Corporation of Hardened 1060 steel.*

** *Including fin area.*

A least square procedure (as discussed in Reference 1) was set up to determine the best values of a, b, and n. Actually, some judgment on the ballistic limits of skin and clothing helped to establish the value of the threshold parameter, b. Note that when $MV_o^{3/2} = b$ then $P_{hk} = 0$.

The tables in Appendix B list values of the parameters a, b and n for four tactical roles (Defense ≤ 30 seconds, Assault ≤ 30 seconds and ≤ 5 minutes and Supply ≤ 1/2 day) for the helmeted, nude soldier, and for the soldier clothed in the American winter uniform (with helmet) and boots; these relations are plotted in Appendix C.

The transformation of the criteria from the nude soldier to the clothed soldier was accomplished quite simply by subtracting from the striking velocity the average velocity lost by the missile while traversing the clothing and/or boots. Table XI is a tabulation of these losses in velocity.

The criteria (which include various levels of incapacitation, i.e., 25%, 50%, 75%, 100%) are not stringent enough when applied to the design and/or evaluation of "personal" type weapons such as pistols, hand grenades, cannister ammunition, anti-personnel mines, rifles, etc. Because of close engagement ranges associated with such weapons their effectiveness should be based only on hits that would cause complete incapacitations. In this instance P_{hk} is defined as the probability that a random, penetrating hit will result in a complete loss in the ability of the soldier to fight. Hence, Appendix B includes values of the parameters for 100% incapacitation for Defense ≤ 30 seconds, Assault ≤ 30 seconds, and Assault ≤ 5 minutes.

At striking velocities of approximately 3000 fps, both the 1.7- and 7.2-grain flechettes started tumbling, that is, rotated end-over-end rapidly, shortly after penetrating tissue. The average depth of tissue penetration to tumbling was 4.1 and 5.0 cm respectively for the 1.7 and 7.2. On the other hand, the 15.2-grain flechette at 4000 fps yawed violently after approximately 8.0 cm of travel in tissue but usually did

TABLE XI

(CONFIDENTIAL) Retardation Data (U)

Missile Weight Grains	Striking Velocity fps	Loss in Velocity (fps) Clothing[a]	Boots	Helmet[b]	Ballistic Limit (fps) Clothing[a]	Boots	Helmet	Skin in Situ
				SPHERE				
.85	1000	390	175	1000	902	593	2757	281
	3000	175	150	2072				
	5000	325	[c]270	[c]3088				
				CUBES				
2.1	1000	320	190	1000	850	567	2892	310
	3000	287	255	1954				
	5000	441	[c]485	2040				
16	1000	135	100	1000	605	419	1457	206
	3000	150	150	870				
	5000	250	220	[c]1550				
225	500	70	43	500	349	237	758	155
	1000	34	25	380				
	2500	[c]≤34	[c]≤25	[c]323				
				FLECHETTES				
1.7	500	N.A.	N.A.	500	474	433	[d]C=2473	202
	2000	[c]48	N.A.	2000			R=2694	
	4000	25	N.A.	794				
7.2	500	[c]65	N.A.	500	361	305	[d]C=871	172
	2000	60	N.A.	325			R=966	
	4000	25	N.A.	[c]245				
15.2	500	[c]69	N.A.	500	351	257	C=912	181
	2000	45	N.A.	273			R=912	
	4000	[c]≤20	N.A.	190				

a. Six-layer winter uniform.

b. Helmet with nylon liner.

c. Derived by interpolation or extrapolation

d. C = Crown, R = Rim.

not tumble end-over-end as did the 1.7- and 7.2-grain flechettes. Thus, a distinction is made in that the 15.2-grain flechette is not considered to be a "tumbler" in the strict sense of the word.

The above suggests that weight is a limiting factor in attaining desirable tumbling qualities, at least for the series of flechettes tested. However, this is only valid if restricted to homogeneous materiel, as a few experiments with an 18-grain bimetallic flechette show that tumbling can occur early in the target even at velocities lower than 2000 fps.

The L/D (length over diameter) ratio probably plays a role in inducing tumbling. The L/D ratios of the 1.7 and 7.2 (150 and 153) are slightly higher than that of the 15.2 (144). But, a short 10-grain experimental flechette with an L/D = 126 has proved to be a good early tumbler.

Another cause of early and rapid tumbling of flechettes in tissue and gelatin, is the inducement of bending and distortion of the flechette upon impact with the target at the higher velocities. Such distortions have been observed for the 1.7 and 7.2 flechettes as well as other experimental flechettes of 13 grains and less. On the other hand, bending and distortion of the 15-grain flechette was not as extensive.

Tumbling characteristics are also affected by the shape of the nose of the flechettes and its hardness. Blunt nose flechettes usually are quite stable in the target even at velocities greater than 3000 fps. Also the noses of soft steel flechettes (30-40 Rockwell) become blunted (flatten out) at high striking velocities and the flechettes are relatively stable.

Generally speaking, in order to qualify as a good tumbler, a homologous flechette should weigh no more than 13 grains, be of mild steel and possess a sharp point. Actually, it has been found that an acute, compound point is most desirable.

In view of the previous comments, wound ballisticians and weapon systems analysts are cautioned not to consider a flechette in the tumbling category solely on the basis that its striking velocity approaches or

exceeds 3000 fps. However, once a flechette has been defined as a tumbler, in the strict sense, the values of a, b and n given in the tables are applicable.

The 15.2-grain flechette was not considered to be a tumbler and therefore was not included in the analysis. The criteria are based specifically on incapacitations derived for the 1.7- and 7.2-grain flechettes at 4000 fps. It is suggested that the criteria for tumbling flechettes be limited to apply to weights between 1.7 and 13 grains and for striking velocities exceeding 3000 fps.

Because of insufficient datum points the values of the parameter b for the tumbling flechettes were chosen arbitrarily to be equal to those for the non-tumbling flechette. The dashed portion of the curves for the tumbling flechettes merely connect the values b with those solid portions of the curve which are supported by data.

When we account for all levels of incapacitation (0, .25, .50, .75, and 1.00) the wounding potential of the tumbling flechette is in general about 10% greater than that for the steel fragments. However, for some anatomical subdivisions, the tumbler is not as potentially incapacitating. In the arms, for example, the P_{hk} for tumblers is less than that for fragments because the flechette must penetrate some minimum distance before tumbling occurs. Hence, in the case of the upper extremities, the flechette is well into or through an arm before any appreciable tumbling occurs. In contrast, the P_{hk}'s for tumblers are greater for lower extremities than those of the fragment, because within the larger cross-sectional area of the legs, there is a sufficient tract length in which the flechette may tumble and thus be more effective.

Another phenomenon, which appears unique at first glance, is concerned with the performance of the non-tumbling flechette in the pelvic region. In all tactical roles, the non-tumbling flechette has a higher probability of incapacitating in the pelvic subdivision than the chunky fragment, at least for the lower and mid-range values of the parameter $mv^{3/2}$. This occurs because bone structures are more dense in this region

of the body and the flechette's superior ability to penetrate bone allows it to get to other organs, such as blood vessels and arteries, with more residual velocity (energy). The smaller fragments are either stopped completely or lose most of their energy in traversing the bone. Additionally, a stable flechette becomes unstable after penetrating or glancing off bone, and in the assessment procedure, is considered a tumbler after striking bone.

Early, during the animal experimental firings with flechettes, it was found that the superior penetrating ability of the missile would allow it to reach every major organ within the human body at velocities of 3000 and 4000 fps, and, unless bone were encountered, any of the three flechettes could traverse the body even at 500 fps. As a result, in projecting flechettes through anatomical cross sections in order to determine the fraction of the total mean presented body area vulnerable to specific gradations of wounding, it was possible in many instances to identify wound classes without recourse to the stepwise process of tissue retardation. In the case of fragments, however, the wound tracts were incrementally evaluated to determine velocity decay as the missile encountered and perforated each type of tissue and organ.

In projecting the imaginary wound tracts through the cross-sectional anatomy charts, personnel of the Biophysics Division credited the larger missiles at the higher velocities with wound tracts greater than the actual width of the missile. Table XII shows the increase in mean presented area of the body which resulted when projection was performed to account for missile size.

WILLIAM KOKINAKIS

JOSEPH SPERRAZZA

(UNCLASSIFIED) TABLE XII

Wt. of Missile grains	Missile Bite cm.	Mean Presented Body Area cm^2
	FRAGMENTS	
0.85	0.0	5144
2.1	0.4	5310
16.0	0.8	5481
225.0	1.6	5837
	FLECHETTES*	
1.7 at 500 + 2000 fps	0.0	5144
at 4000 fps	0.3	5144
7.2 at 500 + 2000 fps	0.2	5312
at 4000 fps	0.5	5312
15.2 at 500 + 2000 fps	0.3	5396
at 4000 fps	0.5	5396

* At the tumbling velocity of 4000 fps, the larger missile bite was considered only after the flechette commenced tumbling. Prior to start of tumble, the smaller missile bite was used.

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APPENDICES

(UNCLAS) A. DEFINITION OF TACTICAL SITUATIONS

(SECRET) B. INDEX AND TABLES OF PARAMETERS (a, n, b) FOR CURVES OF P_{hk} (U)

(SECRET) C. INDEX AND CURVES OF P_{hk} VERSUS PROJECTILE WEIGHT AND STRIKING VELOCITY (U)

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APPENDIX A

(UNCLASSIFIED) DEFINITION OF TACTICAL SITUATIONS

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Assault: For purposes of data application, the tactical situation of assault is considered to be strictly on a company operations level requiring each participating soldier to engage in the maximum type of physical activity. It is postulated that a typical standard type of assault action would be taking place. Two platoons, with one held in reserve, will attack an enemy position at point x approximately 200 - 300 yards from the initial positions of the attacking platoons. The standard procedure of one platoon attacking frontally with the other platoon on the enemy's flank is considered to prevail in such an operation. Each platoon gives cover fire while its partner advances. Certainly no more than 48 hours and probably much less will be allowed for such an operation either to succeed or fail before regrouping prior to another attempt. In such a situation one can readily realize the host of physical activities which would occur. However, an attempt has been made to choose what is considered to be the most important physical requirements necessary for the average advancing assault soldier. In this situation, locomotion forward to meet the enemy is more than implied. Out of various standard forms of locomotion such as crawling, walking, dragging or running, running was considered to be the form most necessary for such an engagement. This choice was substantiated as being closest to reality in informal discussions with Field Forces representatives. In addition to being able to run, the soldier must be able to load, aim, and fire a rifle or carbine in the accustomed manner. To be able to see, hear, think, and communicate with others are also requirements in an active stress situation.

Defense: Again the company level of operations has been chosen. This situation is considered to be static, with men well dug in, and having maximum shelters for protection.

It is postulated that locomotion in such a situation is much less a compelling requirement than in assault. The total distance over which the defensive soldier is likely to move is approximately 10 to 20 feet, but mobility such as crawling or walking with difficulty was considered to be entirely adequate as a form of movement. In addition, the soldier is required to load and fire his rifle, but fr n a fixed position requiring less upper extremity dexterity than in the assault situation. The requirements of being able to see, hear, think, and communicate with others still exists.

Supply: The supply situation offers considerably more difficulty in the evaluation of human incapacitation, for one finds it difficult to delineate specific work requirements in such a field of diverse activities. An attempt was made to choose only one specific work situation. This choice is one of a soldier who is standing in an ammunition line receiving light loads from his right and passing them on to the man to his left. The implication here is that he must assume a standing position, utilize his arms, but not engage in any sort of locomotion. This was considered to be somewhat a realistic front line supply situation engaged in at one time or another by a typical supply "ammo" bearer. Although only one typical situation was chosen as an illustrative example of the supply situation, one can, from a much broader sense, evaluate incapacitation in this stress situation. If one considers supply situations far in the rear of actual combat, one could consider just about all extremity disability as totally incapacitating, as an injured man would likely report to some dispensary for treatment soon after injury.

Reserve: Our reserve situation implies a company of men ready to be either committed to an assault or defensive situation as already described. However, prior to commitment, this type of reserve pool is considered physically inactive. It is considered that any wound of even a relatively innocuous type will produce a greater degree of incapacitation than the same wound sustained during an assault or defensive situation. This reasoning is based on the assumption that men who sustain wounds while in a reserve pool are much less likely to be committed by their company commanders to the above circumstances.

APPENDIX B

(SECRET) INDEX AND TABLES OF PARAMETERS (a, n, b) FOR CURVES OF P_{hk} (U)

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(CONFIDENTIAL) INDEX OF TABLES

Table	Projectile	Tactical Role	Part of Body
I	Fragment	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Nude, entire and each anatomical subdivision.
II	Fragment	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Clothed, entire and each anatomical subdivision.
III	Stable Flechette	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Nude, entire and each anatomical subdivision.
IV	Stable Flechette	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Clothed, entire and each anatomical subdivision.
V	Tumbling Flechette	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Nude, entire and each anatomical subdivision.
VI	Tumbling Flechette	Defense ≤ 30 seconds Assault ≤ 30 seconds Assault ≤ 5 min. Supply ≤ 12 hours	Clothed, entire and each anatomical subdivision.
VII	Fragment, Stable and Tumbling Flechette	100% Incapacitation for Defense ≤ 30 seconds, Assault ≤ 30 seconds, & Assault ≤ 5 min.	Nude, entire
VIII	Fragment, Stable and Tumbling Flechette	100% Incapacitation for Defense ≤ 30 seconds, Assault ≤ 30 seconds, & Assault ≤ 5 min.	Clothed, entire
IX	Fragment, Stable and Tumbling Flechette	100% Incapacitation for Defense ≤ 30 seconds	Clothed, entire and each anatomical subdivision.

TABLE I

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Steel Fragments (U)

(Soldier is assumed to be nude)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	8.7026×10^{-3}	.36023	26,500	.0651
Thorax	2.1001×10^{-3}	.27000	26,780	.1304
Abdomen	7.3623×10^{-4}	.46494	26,780	.1065
Pelvis	6.8001×10^{-6}	.74407	23,500	.1156
Arms	1.4293×10^{-3}	.42552	26,780	.2045
Legs	6.3251×10^{-4}	.46675	26,700	.3778
Entire Body	1.6788×10^{-3}	.41356	26,500	
	Assault ≤ 30 sec.			
Head and Neck	7.5501×10^{-3}	.37518	26,500	
Thorax	1.2809×10^{-2}	.31650	26,700	
Abdomen	5.0675×10^{-4}	.50878	26,780	
Pelvis	1.5833×10^{-5}	.72599	23,500	
Arms	5.1702×10^{-3}	.36032	26,780	
Legs	3.4535×10^{-4}	.57226	26,400	
Entire Body	1.4992×10^{-3}	.45492	26,500	
	Assault ≤ 5 min.			
Head and Neck	8.1464×10^{-3}	.38955	26,500	
Thorax	2.2652×10^{-2}	.28542	26,700	
Abdomen	2.1028×10^{-3}	.44292	26,780	
Pelvis	1.5984×10^{-4}	.58732	23,500	
Arms	3.6001×10^{-3}	.40015	26,500	
Legs	4.3226×10^{-4}	.56420	25,800	
Entire Body	2.0785×10^{-3}	.44545	25,800	
	Supply ≤ 12 hrs.			
Head and Neck	4.5911×10^{-2}	.27078	26,780	
Thorax	3.7620×10^{-2}	.26330	26,780	
Abdomen	1.0607×10^{-1}	.20885	25,800	
Pelvis	4.9274×10^{-3}	.38392	23,500	
Arms	5.9909×10^{-4}	.53665	23,500	
Legs	3.6130×10^{-4}	.56185	23,500	
Entire Body	3.4423×10^{-3}	.41845	23,500	

* r is ratio of the presented area of a Part to the entire body.

TABLE II

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Steel Fragments (U)

(Soldier with helmet and winter clothing)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	2.6648×10^{-4}	.57884	20,000	.0651
Thorax	1.7955×10^{-2}	.27859	45,000	.1304
Abdomen	5.1602×10^{-4}	.48523	43,500	.1065
Pelvis	4.0293×10^{-6}	.77314	36,500	.1156
Arms	8.4126×10^{-4}	.45662	30,500	.2045
Legs	5.3116×10^{-4}	.47749	31,400	.3778
Entire Body	8.8771×10^{-4}	.45106	31,400	
	Assault ≤ 30 sec.			
Head and Neck	2.1063×10^{-4}	.59981	20,000	
Thorax	1.0479×10^{-2}	.32779	40,500	
Abdomen	3.4436×10^{-4}	.53050	42,000	
Pelvis	1.0015×10^{-5}	.75050	41,000	
Arms	3.1468×10^{-3}	.39054	30,000	
Legs	3.0833×10^{-4}	.57749	30,000	
Entire Body	7.6442×10^{-4}	.49570	31,000	
	Assault ≤ 5 min.			
Head and Neck	2.1641×10^{-4}	.62684	20,000	
Thorax	1.9060×10^{-2}	.29474	44,000	
Abdomen	1.7401×10^{-3}	.45191	45,000	
Pelvis	1.0855×10^{-4}	.60862	39,000	
Arms	2.1247×10^{-3}	.43224	31,100	
Legs	3.5277×10^{-4}	.57631	30,000	
Entire Body	1.0454×10^{-3}	.48781	31,000	
	Supply ≤ 12 hrs.			
Head and Neck	6.0806×10^{-4}	.55367	20,000	
Thorax	3.2873×10^{-2}	.27050	45,000	
Abdomen	9.2431×10^{-2}	.21660	43,500	
Pelvis	4.0060×10^{-3}	.39513	40,500	
Arms	3.6448×10^{-4}	.56628	29,000	
Legs	3.1099×10^{-4}	.57085	29,000	
Entire Body	2.1973×10^{-3}	.44350	29,000	

* r is ratio of the presented area of a Part to the entire body.

TABLE III

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Non-Tumbling Flechette (U)

(Soldier is assumed to be nude)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	4.4497×10^{-5}	.71730	17,000	.0651
Thorax	1.8074×10^{-6}	.85827	0	.1304
Abdomen	9.9419×10^{-8}	1.01934	0	.1064
Pelvis	4.7265×10^{-5}	.60399	11,000	.1156
Arms	3.5068×10^{-4}	.45248	0	.2045
Legs	6.2746×10^{-5}	.57247	10,000	.3778
Entire Body	5.5791×10^{-5}	.59839	10,000	
	Assault ≤ 30 sec.			
Head and Neck	4.4106×10^{-5}	.71887	17,000	
Thorax	5.3687×10^{-6}	.80156	10,000	
Abdomen	2.1914×10^{-6}	.81548	0	
Pelvis	2.5449×10^{-4}	.53043	15,000	
Arms	1.2913×10^{-3}	.39877	16,000	
Legs	9.5249×10^{-5}	.60084	10,000	
Entire Body	1.0590×10^{-4}	.58983	11,000	
	Assault ≤ 5 min.			
Head and Neck	1.3627×10^{-4}	.67313	18,000	
Thorax	2.1605×10^{-3}	.43596	15,000	
Abdomen	6.3702×10^{-4}	.51350	0	
Pelvis	2.0479×10^{-3}	.43161	15,000	
Arms	7.2379×10^{-4}	.47249	16,000	
Legs	1.9488×10^{-4}	.57565	15,000	
Entire Body	6.4241×10^{-4}	.50256	14,000	
	Supply ≤ 12 hrs.			
Head and Neck	1.5786×10^{-4}	.66436	18,000	
Thorax	3.5758×10^{-3}	.40604	18,500	
Abdomen	4.7248×10^{-4}	.57593	11,000	
Pelvis	2.3060×10^{-3}	.44704	18,000	
Arms	5.5160×10^{-4}	.48814	17,000	
Legs	5.4716×10^{-4}	.50490	18,000	
Entire Body	1.2127×10^{-3}	.46380	17,000	

* r is ratio of the presented area of a Part to the entire body.

TABLE IV

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Non-Tumbling Flechette (U)

(Soldier with helmet and winter clothing)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	4.6872×10^{-7}	1.02621	0	.0651
Thorax	2.2964×10^{-6}	.83907	10,000	.1304
Abdomen	1.1286×10^{-7}	1.00639	10,000	.1065
Pelvis	3.6920×10^{-5}	.61937	13,000	.1156
Arms	3.9447×10^{-4}	.44302	10,000	.2045
Legs	5.0873×10^{-5}	.58621	13,000	.3778
Entire Body	3.6302×10^{-5}	.62548	13,000	
	Assault ≤ 30 sec.			
Head and Neck	4.8562×10^{-7}	1.02534	0	
Thorax	4.5872×10^{-6}	.81054	13,000	
Abdomen	1.6640×10^{-6}	.83381	10,000	
Pelvis	2.1342×10^{-4}	.54075	18,000	
Arms	1.1204×10^{-3}	.40774	18,000	
Legs	7.0968×10^{-5}	.62031	12,000	
Entire Body	7.6217×10^{-5}	.61076	13,000	
	Assault ≤ 5 min.			
Head and Neck	1.1356×10^{-5}	.83353	14,000	
Thorax	1.7359×10^{-3}	.45038	18,000	
Abdomen	7.6605×10^{-4}	.49968	10,000	
Pelvis	1.6556×10^{-3}	.44541	18,000	
Arms	7.4722×10^{-4}	.46931	20,000	
Legs	1.8186×10^{-4}	.57960	18,000	
Entire Body	5.1222×10^{-4}	.51658	17,000	
	Supply ≤ 12 hrs.			
Head and Neck	5.2662×10^{-6}	.89243	10,000	
Thorax	3.3084×10^{-3}	.40998	23,000	
Abdomen	4.3368×10^{-4}	.57984	16,000	
Pelvis	1.9224×10^{-3}	.45788	21,000	
Arms	4.6218×10^{-4}	.49925	20,000	
Legs	4.6397×10^{-4}	.51530	21,000	
Entire Body	8.4626×10^{-4}	.48828	21,000	

* r is ratio of the presented area of a Part to the entire body.

TABLE V

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Tumbling Flechette (U)

(Soldier is assumed to be nude)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	7.8288×10^{-2}	.20942	17,000	.0651
Thorax	1.8084×10^{-3}	.44032	0	.1304
Abdomen	1.0632×10^{-4}	.63570	0	.1065
Pelvis	5.4027×10^{-5}	.64072	11,000	.1156
Arms	8.8893×10^{-4}	.45453	0	.2045
Legs	5.0439×10^{-4}	.47203	10,000	.3778
Entire Body	1.3140×10^{-3}	.43432	10,000	
	Assault ≤ 30 sec.			
Head and Neck	3.1926×10^{-3}	.45325	17,000	
Thorax	4.3175×10^{-3}	.38696	10,000	
Abdomen	1.5864×10^{-4}	.60210	0	
Pelvis	1.1750×10^{-5}	.77044	15,000	
Arms	2.2264×10^{-3}	.40824	16,000	
Legs	9.5436×10^{-5}	.66420	10,000	
Entire Body	1.0582×10^{-3}	.48464	11,000	
	Assault ≤ 5 min.			
Head and Neck	1.1673×10^{-2}	.34408	18,000	
Thorax	4.2752×10^{-3}	.44705	15,000	
Abdomen	9.6232×10^{-5}	.70848	0	
Pelvis	2.4528×10^{-5}	.78672	15,000	
Arms	1.9517×10^{-3}	.43622	16,000	
Legs	2.7056×10^{-4}	.60554	15,000	
Entire Body	7.4080×10^{-4}	.53460	14,000	
	Supply ≤ 12 hrs.			
Head and Neck	1.9271×10^{-2}	.34362	18,000	
Thorax	2.1764×10^{-2}	.30853	18,500	
Abdomen	3.2628×10^{-2}	.31087	11,000	
Pelvis	6.1528×10^{-4}	.57494	18,000	
Arms	3.3384×10^{-4}	.57181	17,000	
Legs	2.5992×10^{-4}	.60132	18,000	
Entire Body	2.1780×10^{-3}	.46169	17,000	

* r is ratio of the presented area of a Part to the entire body.

TABLE VI

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

Tumbling Flechette (U)

(Soldier with helmet and winter clothing)

Part of Body	a	n	b	r*
	Defense ≤ 30 sec.			
Head and Neck	1946×10^{-4}	.68954	0	.0651
Thorax	1.4908×10^{-3}	.45192	10,000	.1304
Abdomen	8.8912×10^{-5}	.64639	10,000	.1065
Pelvis	3.4989×10^{-5}	.66768	13,000	.1156
Arms	7.7820×10^{-4}	.46262	10,000	.2045
Legs	3.8556×10^{-4}	.48819	13,000	.3778
Entire Body	7.4970×10^{-4}	.46969	13,000	
	Assault ≤ 30 sec.			
Head and Neck	1.0258×10^{-4}	.86215	0	
Thorax	3.8183×10^{-3}	.39458	13,000	
Abdomen	1.3279×10^{-4}	.61354	10,000	
Pelvis	7.1670×10^{-5}	.80215	18,000	
Arms	1.7001×10^{-3}	.42537	18,000	
Legs	7.7319×10^{-5}	.67643	12,000	
Entire Body	7.9580×10^{-4}	.50032	13,000	
	Assault ≤ 5 min.			
Head and Neck	2.8605×10^{-5}	.80934	14,000	
Thorax	9.1266×10^{-3}	.35946	18,000	
Abdomen	4.9520×10^{-5}	.75548	10,000	
Pelvis	1.6672×10^{-5}	.81150	18,000	
Arms	1.5598×10^{-3}	.45013	20,000	
Legs	2.0868×10^{-4}	.62196	18,000	
Entire Body	4.6090×10^{-4}	.56622	17,000	
	Supply ≤ 12 hrs.			
Head and Neck	8.2092×10^{-5}	.73511	10,000	
Thorax	1.7615×10^{-2}	.32171	23,000	
Abdomen	2.6219×10^{-2}	.32207	16,000	
Pelvis	5.7651×10^{-4}	.57612	21,000	
Arms	2.5720×10^{-4}	.58841	20,000	
Legs	2.0107×10^{-4}	.61712	21,000	
Entire Body	1.4410×10^{-3}	.48872	21,000	

* r is ratio of the presented area of a Part to the entire body.

TABLE VII

(SECRET) Parameters (a,n,b) for Curve of P_{hk} (U)

(100% Incapacitation)

(Soldier is assumed to be nude)

Situation	a	n	b
	Steel Fragments		
D30	3.0070×10^{-5}	.59127	66,000
A30	2.2516×10^{-5}	.67992	57,000
A5	2.2027×10^{-4}	.55500	26,000
	Non-Tumbling Flechettes		
D30	5.9648×10^{-8}	.95227	18,000
A30	3.3934×10^{-5}	.60867	10,000
A5	1.7280×10^{-5}	.68914	10,000
	Tumbling Flechettes		
D30	1.1515×10^{-5}	.64957	18,000
A30	4.9882×10^{-5}	.63553	10,000
A5	1.3910×10^{-5}	.76009	10,000

TABLE VIII

(SECRET) Parameters (a,n,b) for Curve of P_{hk} (U)

(100% Incapacitation)

(Soldier with helmet and winter clothing)

Situation	a	n	b
		Steel Fragments	
D30	1.4411×10^{-5}	.63345	66,000
A30	9.9557×10^{-6}	.73159	62,000
A5	2.1078×10^{-4}	.55514	40,000
		Non-Tumbling Flechettes	
D30	5.9648×10^{-8}	.95227	18,000
A30	2.6133×10^{-5}	.62527	14,000
A5	1.3859×10^{-5}	.70271	14,000
		Tumbling Flechettes	
D30	1.1515×10^{-5}	.64957	18,000
A30	3.665×10^{-5}	.65548	14,000
A5	1.0349×10^{-5}	.77940	14,000

TABLE IX

(SECRET) Parameters (a,n,b) for Curve of P_{hk}

(Defense 30 seconds, 100% incapacitation) (U)

(Soldier with helmet and winter clothing)

Part of Body	a	n	b	n
		Steel Fragment		
Head and Neck	2.5119×10^{-4}	.55180	0	.0651
Thorax	2.9296×10^{-7}	.93259	50,000	.1304
Abdomen	3.1355×10^{-5}	.62903	310,000	.1065
Pelvis	2.0858×10^{-5}	.62738	245,000	.1156
Arms	7.8606×10^{-5}	.47771	245,000	.2045
Legs	7.5119×10^{-7}	.76824	1,000,000	.3778
Entire Body	1.4411×10^{-5}	.63345	66,000	
		Non-Tumbling Flechette		
Head and Neck	5.1500×10^{-8}	1.15801	0	.0651
Thorax	1.1659×10^{-7}	.96667	48,500	.1304
*Abdomen				
*Pelvis				
*Arms				
*Legs				
Entire Body	5.9648×10^{-8}	.95227	18,000	
		Tumbling Flechette		
Head and Neck	4.0546×10^{-3}	.40206	0	.0651
Thorax	3.4494×10^{-5}	.64419	48,500	.1304
*Abdomen				
*Pelvis				
*Arms				
*Legs				
Entire Body	1.1515×10^{-5}	.64957	18,000	

* Insufficient data points to compute these values.

APPENDIX C

(SECRET) INDEX AND CURVES OF P_{hk} VERSUS PROJECTILE WEIGHT AND STRIKING VELOCITY (U)

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(CONFIDENTIAL) INDEX OF FIGURES

P_{hk} versus $mv^{3/2}$

for

Steel Fragments, Stable and Tumbling Flechettes

Defense ≤ 30 seconds (100% incapacitation only)

22	Entire Body
23	Head and Neck
24	Thorax
25	Abdomen, Fragment only
26	Pelvis, Fragment only
27	Arms, Fragment only
28	Legs, Fragment only

100% Incapacitation Only

29	Assault ≤ 30 seconds
30	Defense ≤ 30 seconds
31	Assault ≤ 5 minutes

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FIGURE 1

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault ≤ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Entire Body

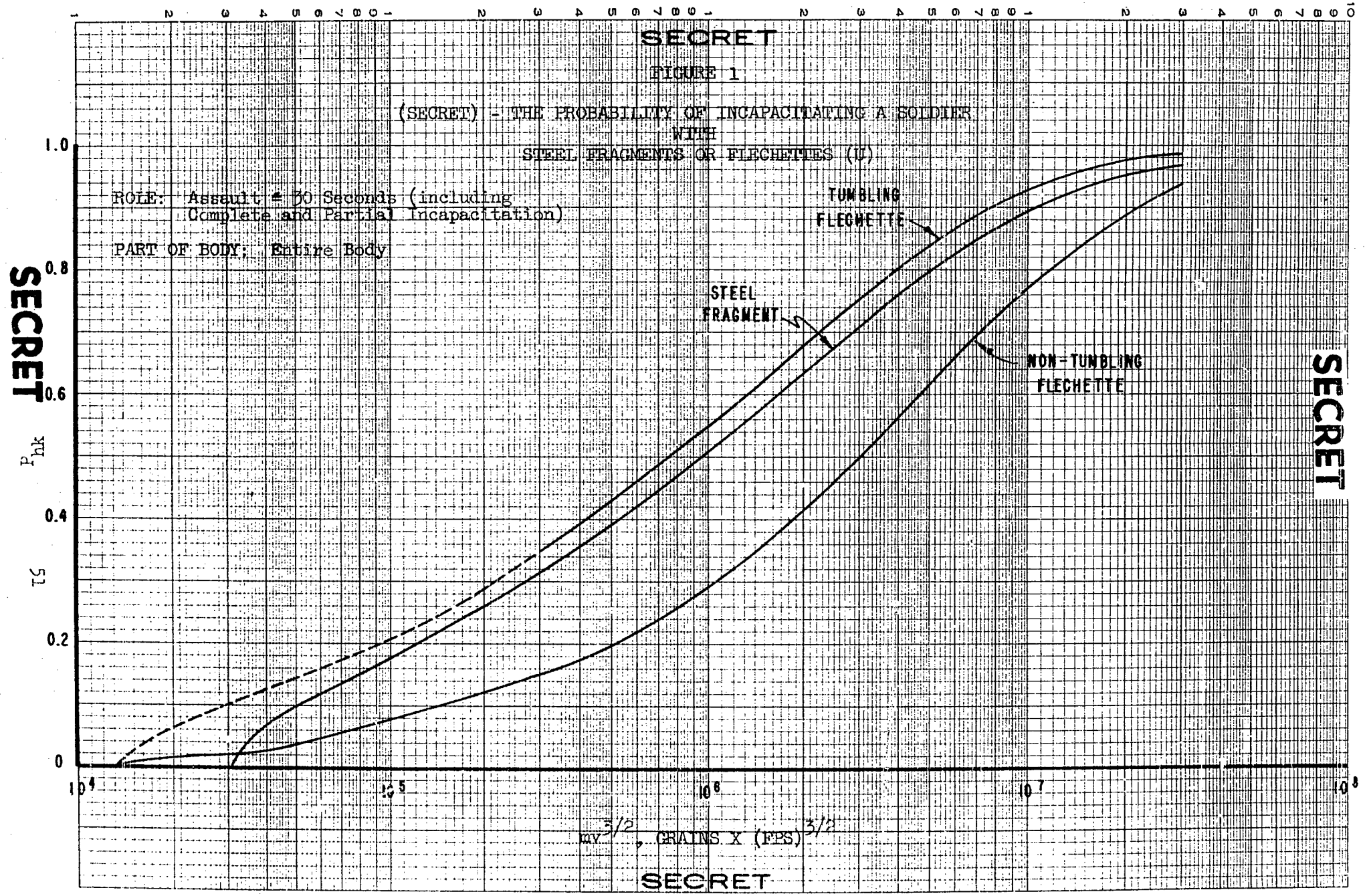

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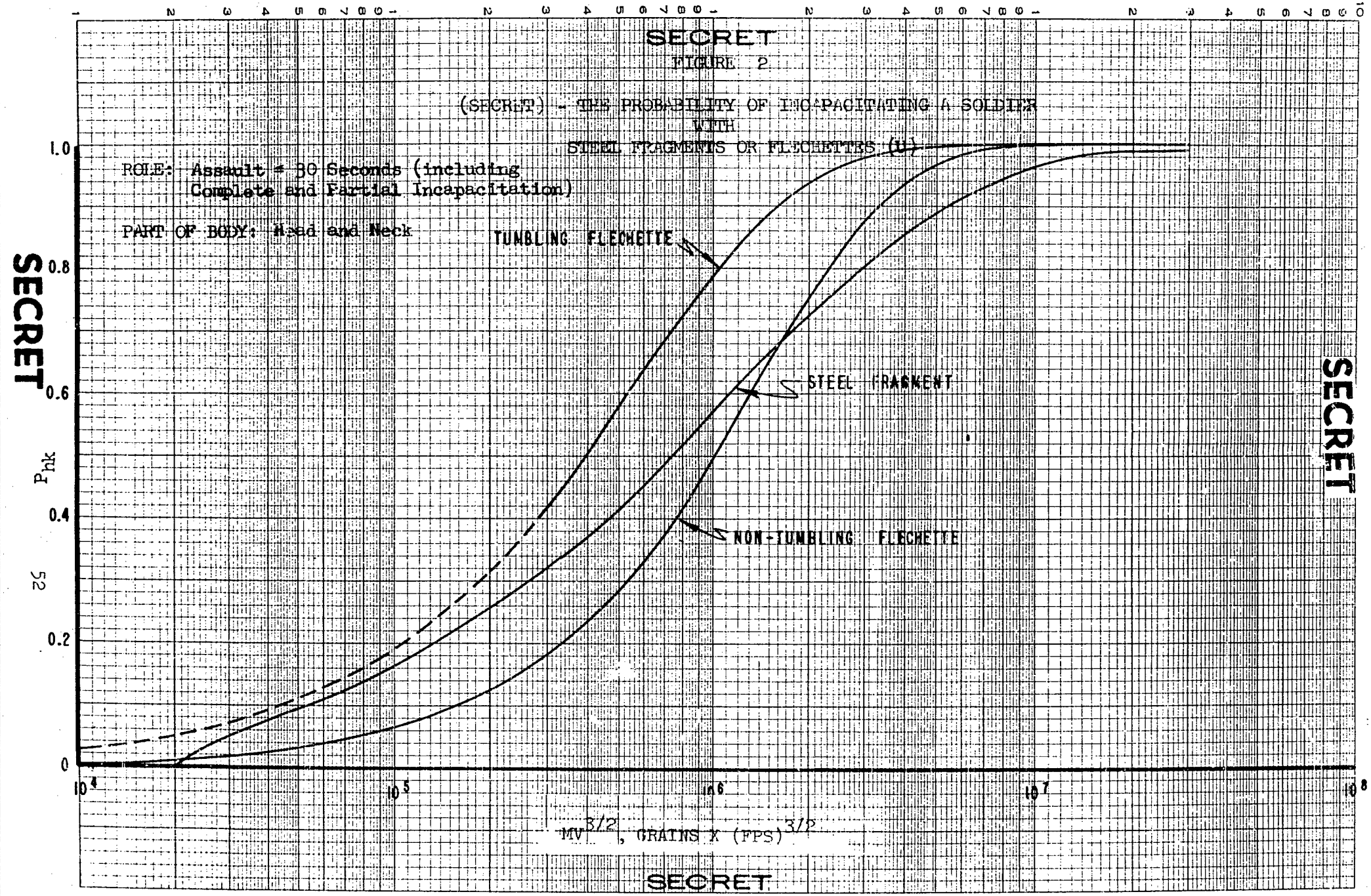
FIGURE 2

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault = 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Head and Neck



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52

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FIGURE 3

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OF FLECHETTES (U)

ROLE: Assault ≤ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Thorax

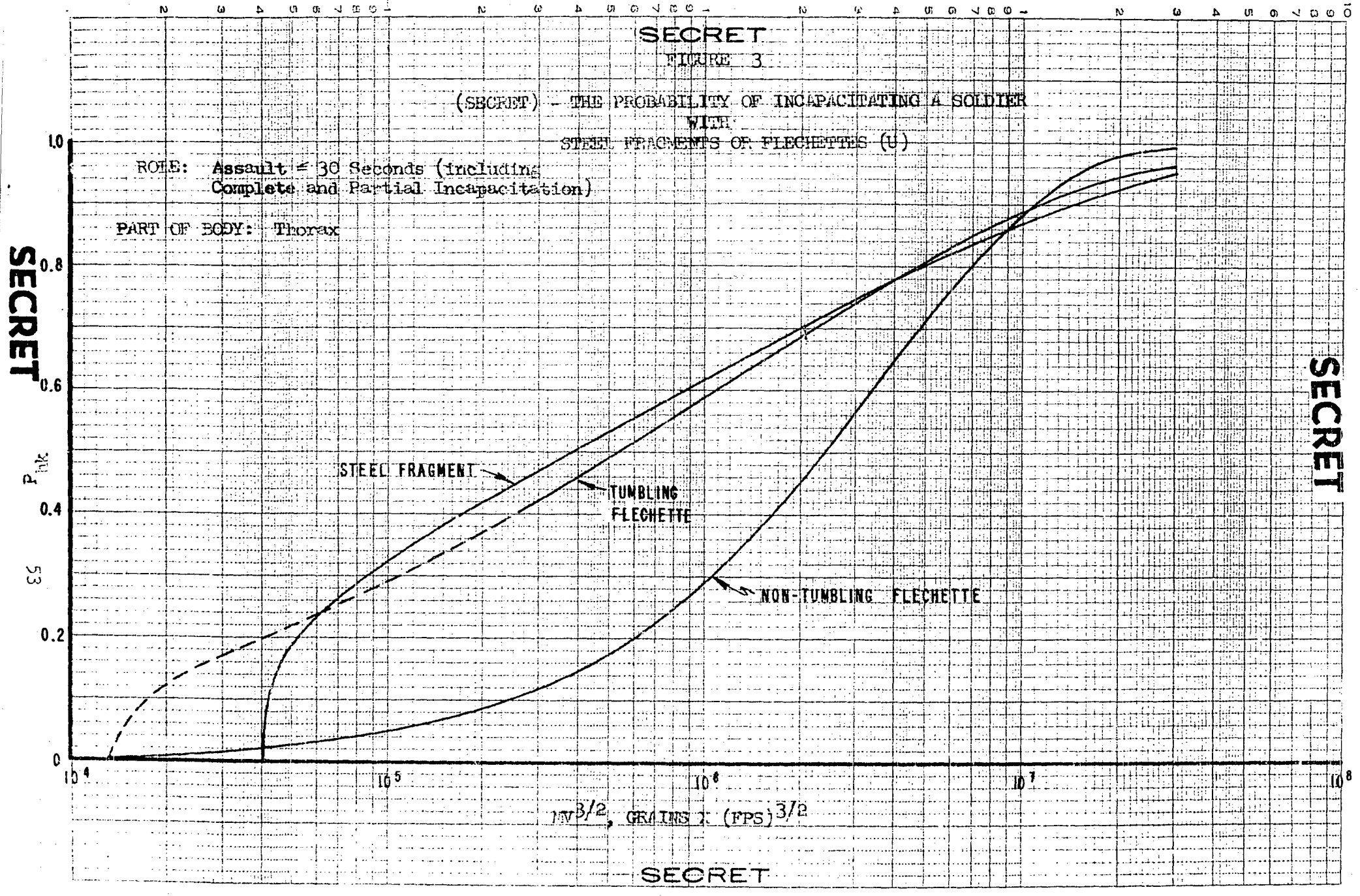

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FIGURE 4

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault ≤ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Abdomen

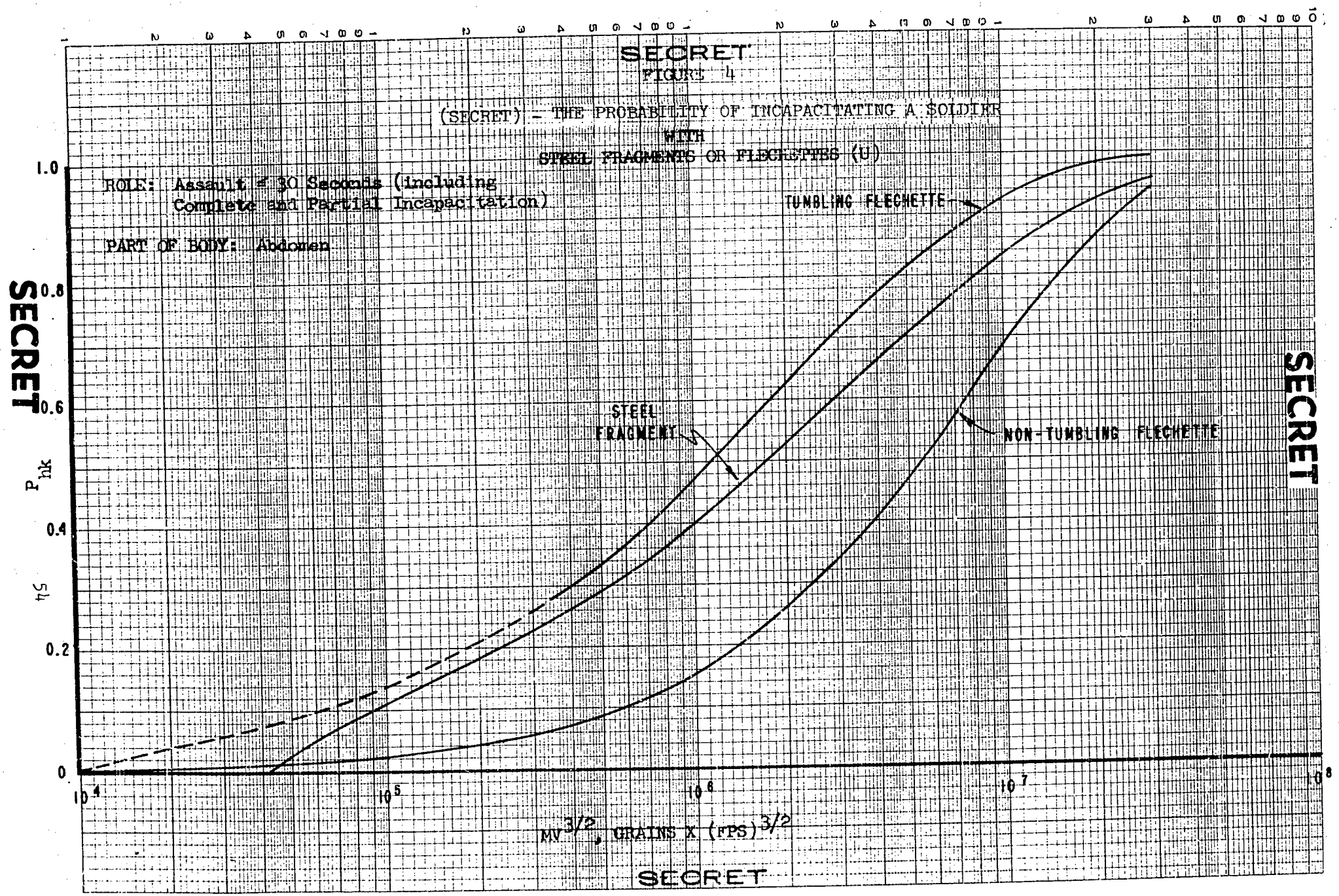

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FIGURE 5

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault ≤ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Pelvis

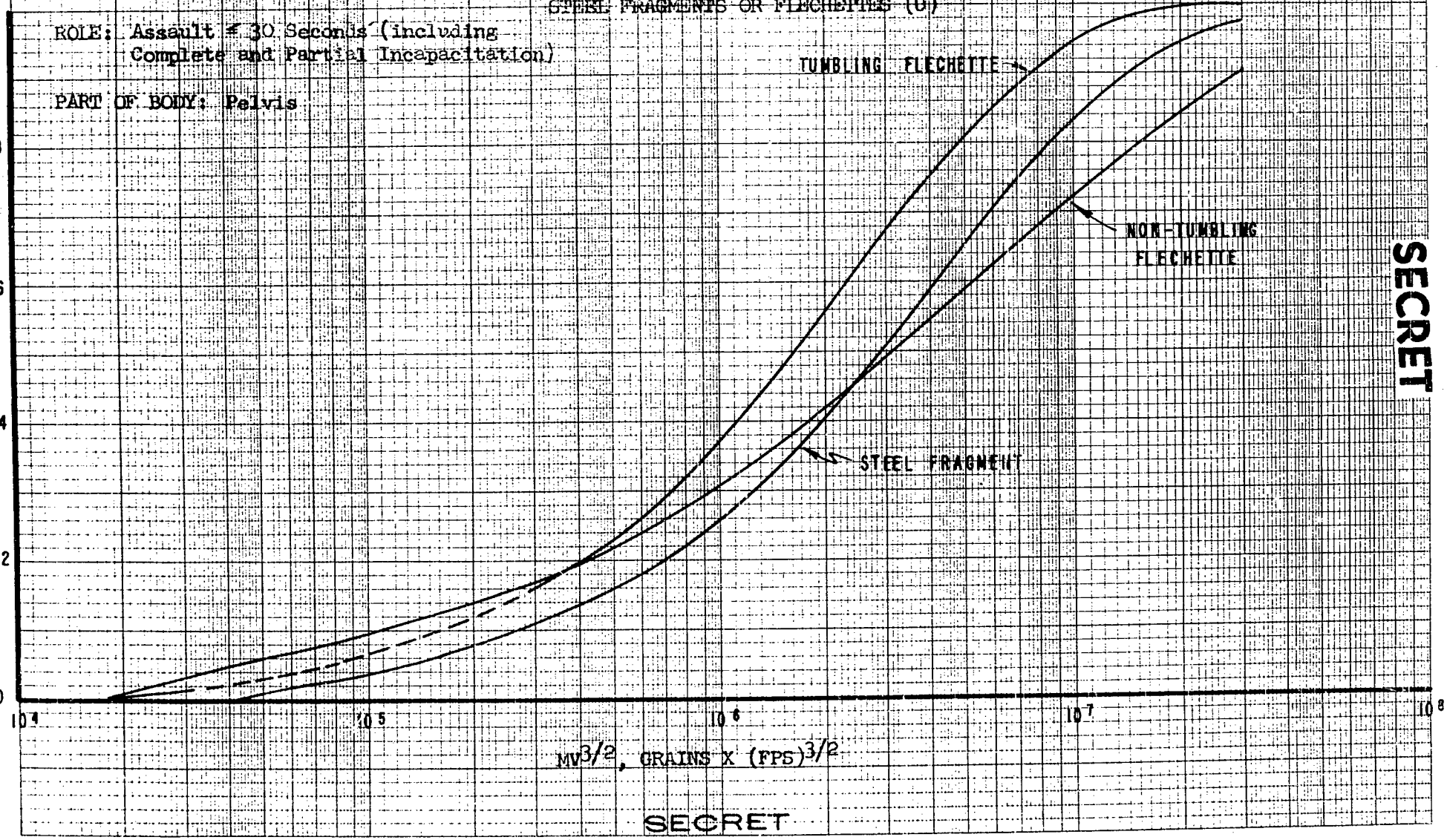

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FIGURE 6

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

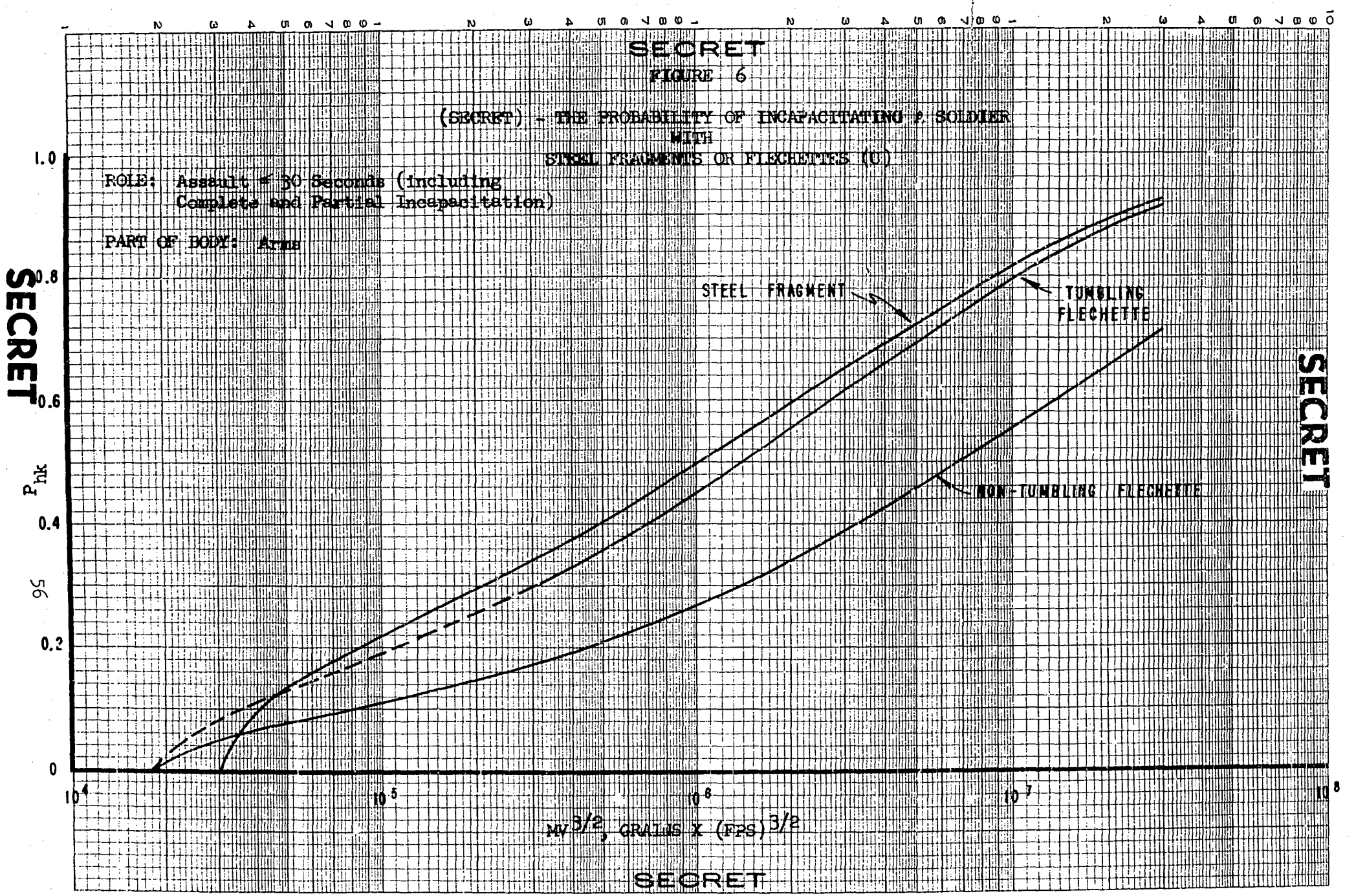

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FIGURE 7

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault - 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Legs

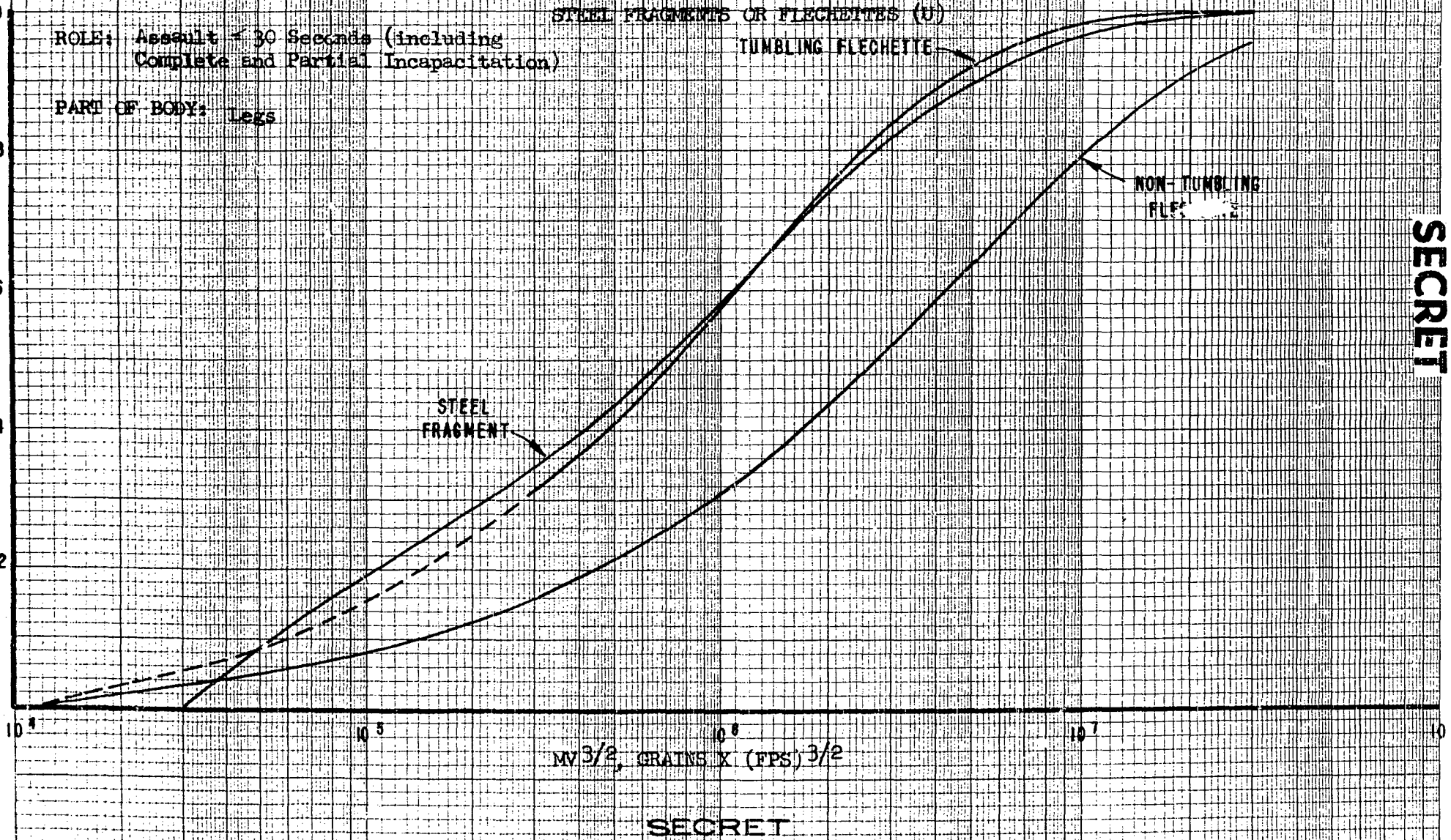

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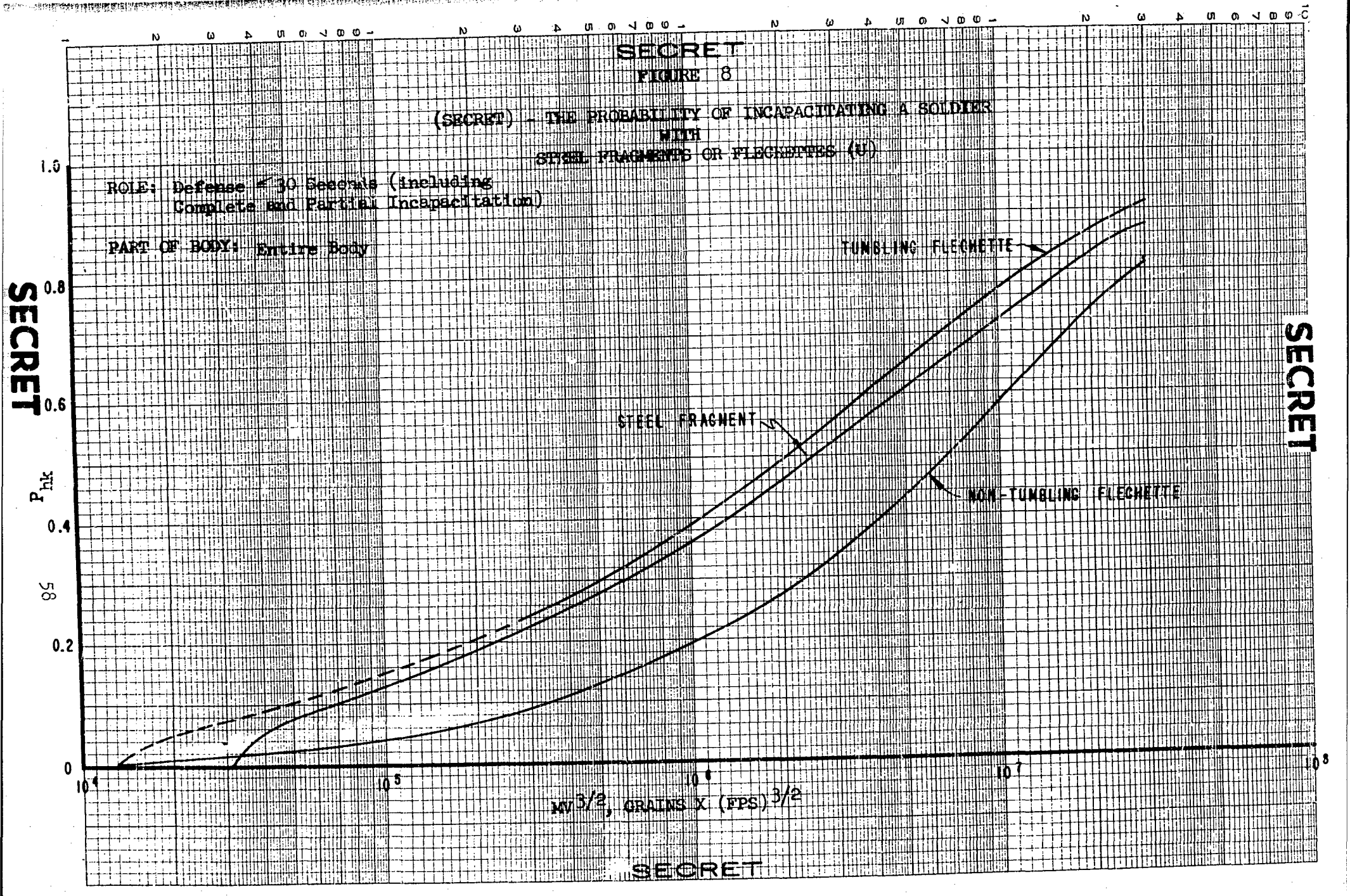
FIGURE 8

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Entire Body



58

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FIGURE 9

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Head and Neck

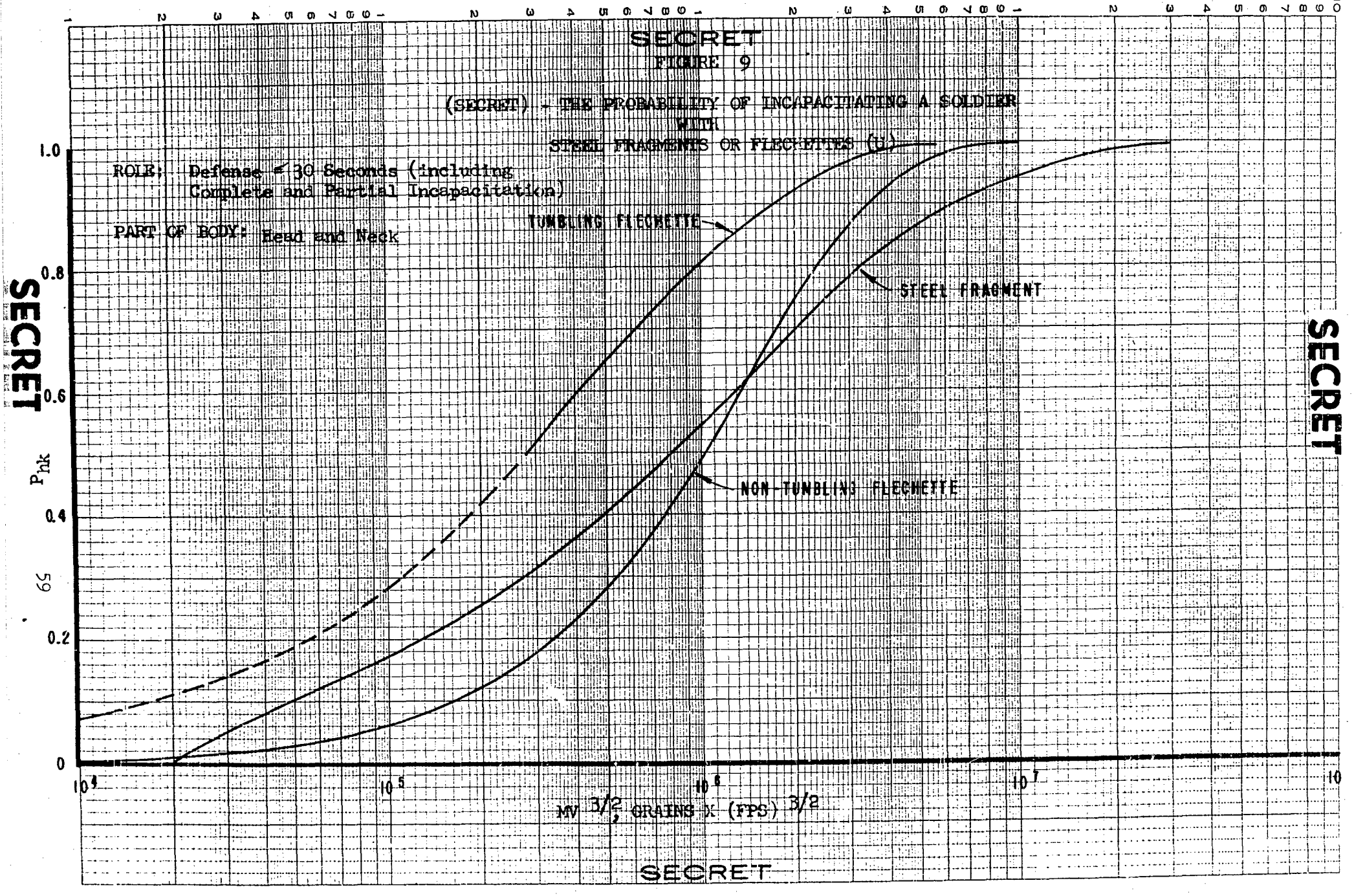

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FIGURE 10

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense - 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Thorax

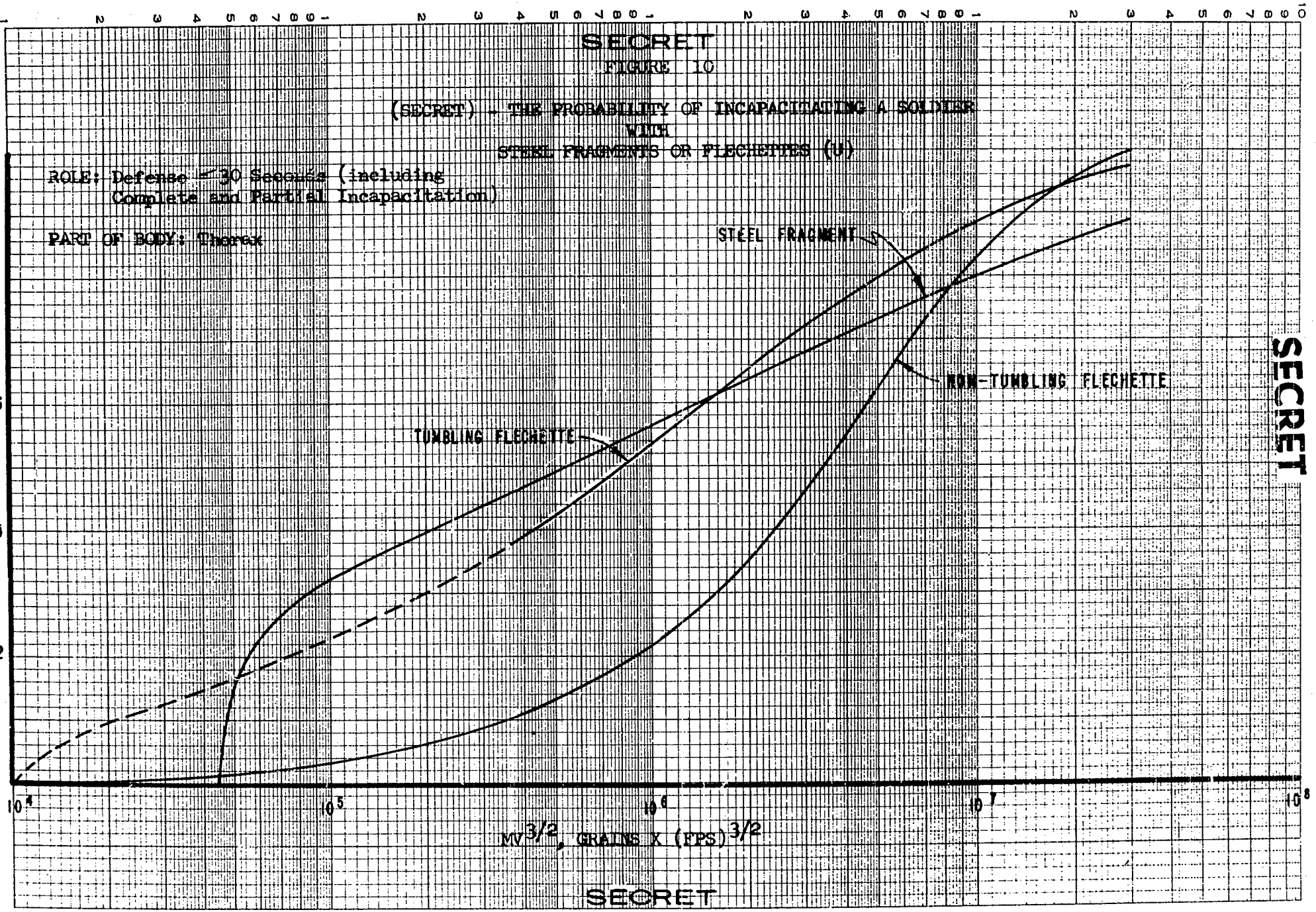

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FIGURE 11

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense ≠ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Abdomen

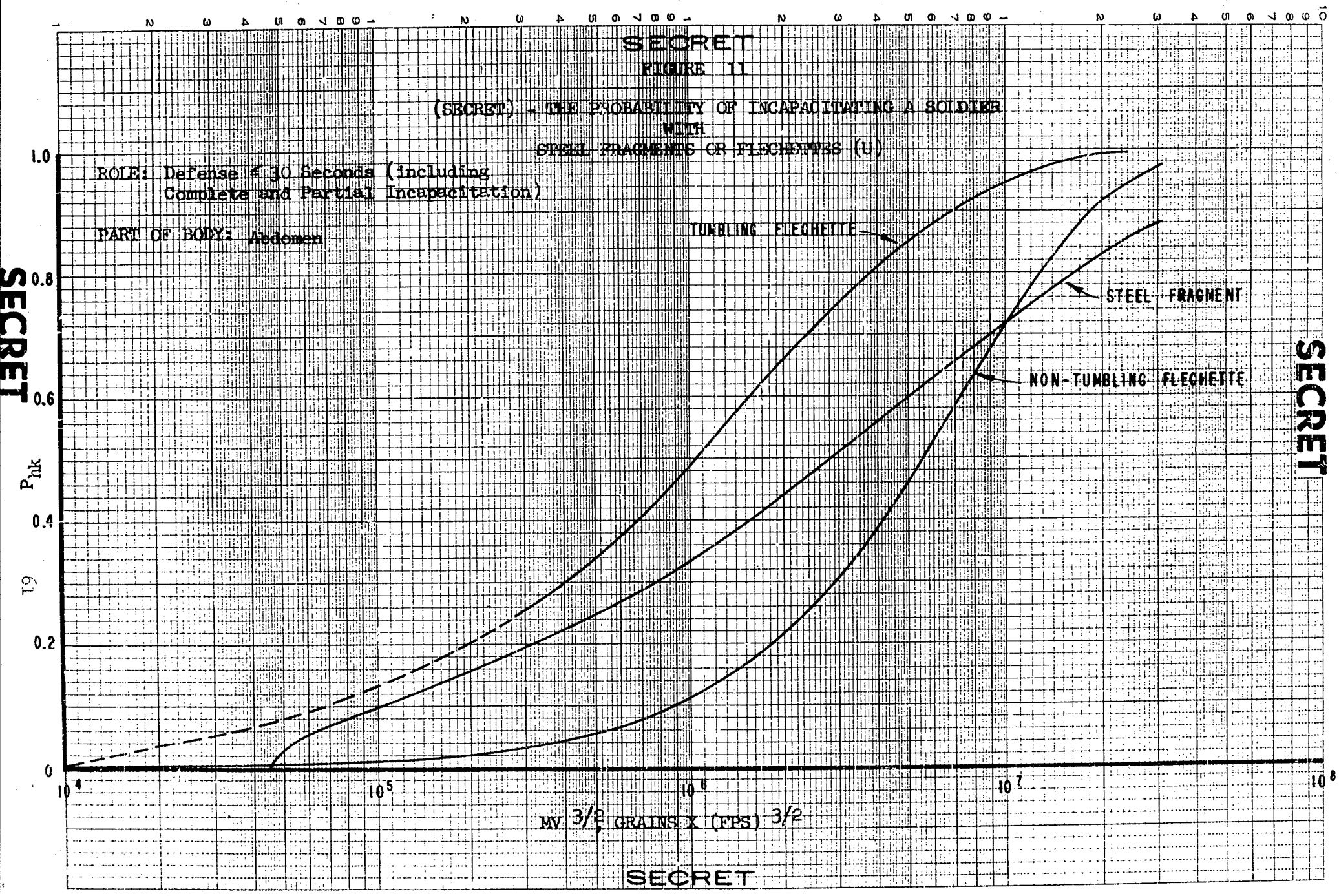

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FIGURE 12

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Pelvis

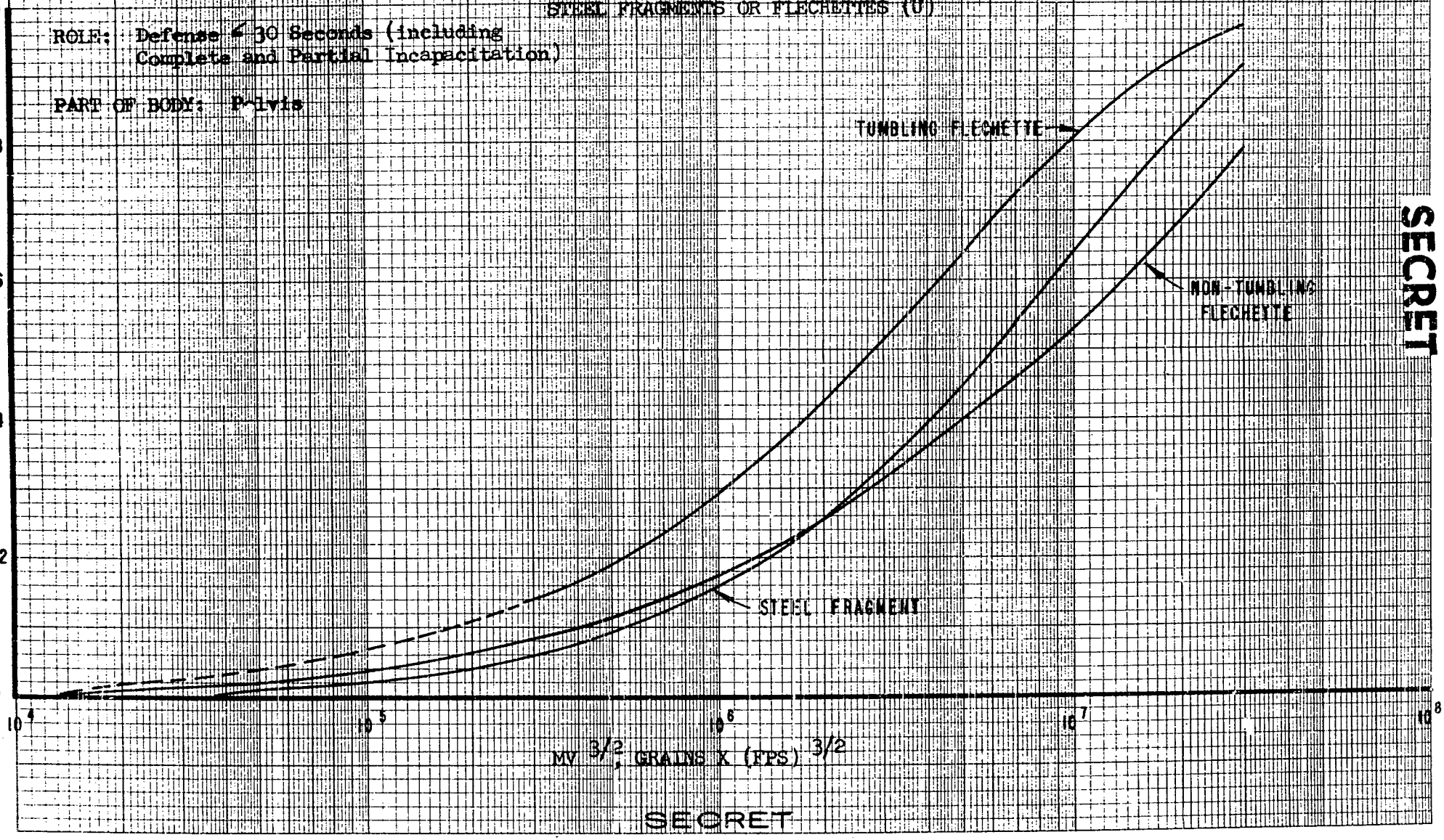

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FIGURE 13

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense ≤ 30 Seconds (including Complete and Partial Incapacitation)

PART OF BODY: Arms

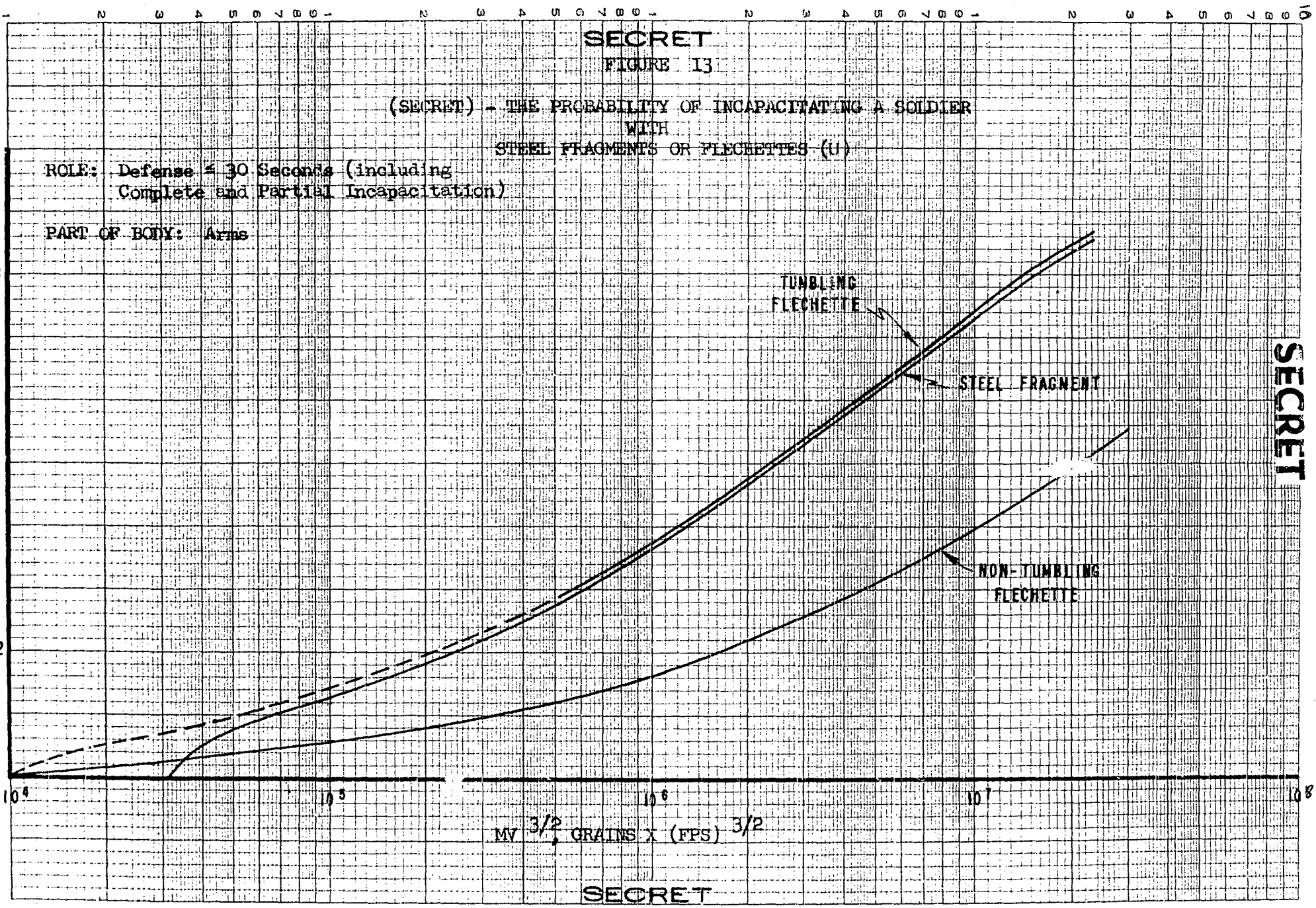

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FIGURE 14

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

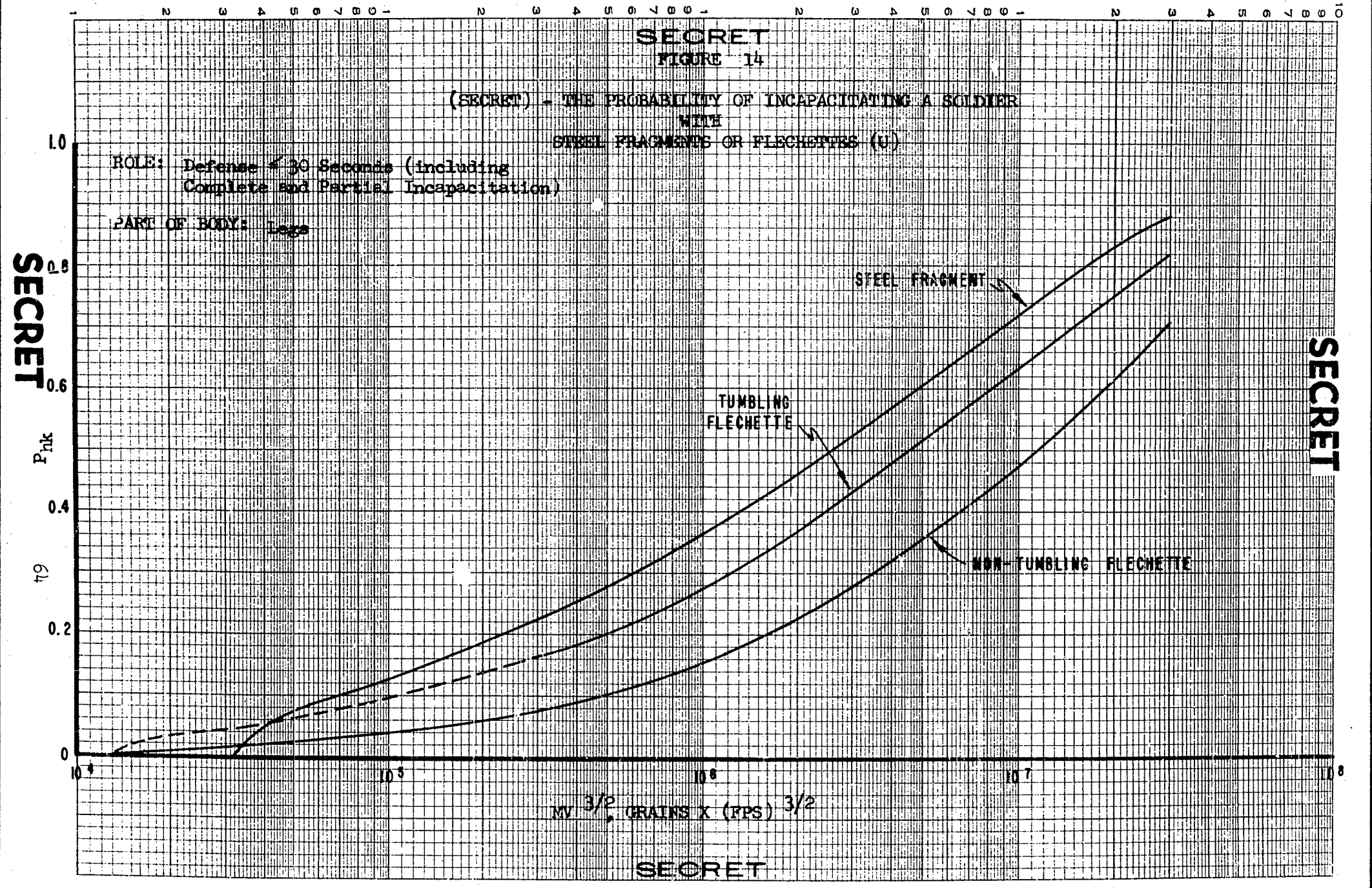

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FIGURE 15

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault < 5 Minutes (including Complete and Partial Incapacitation)

PART OF BODY: Entire Body

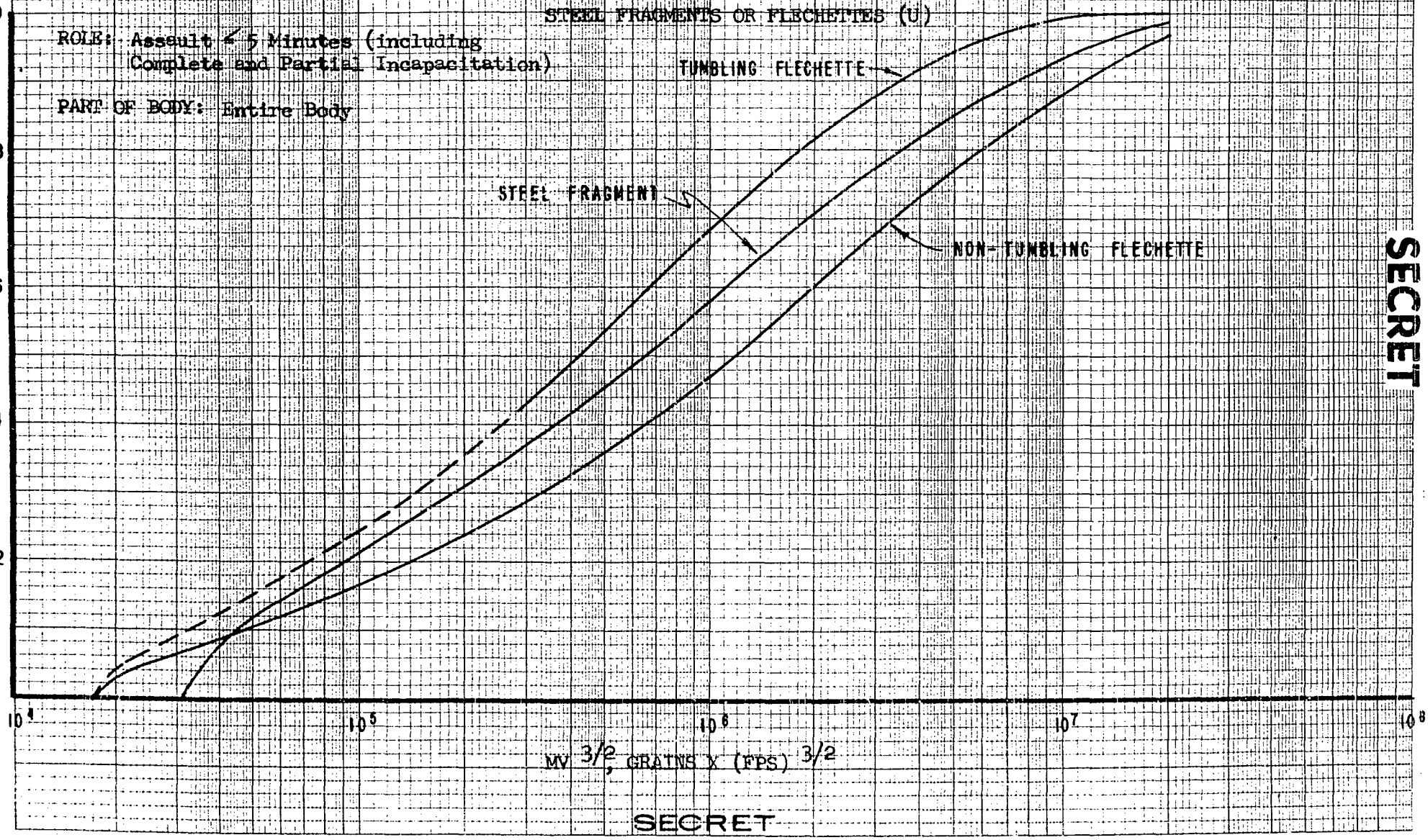

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FIGURE 16

(SECRET) – THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault < 5 Minutes (including Complete and Partial Incapacitation)

PART OF BODY: Head and Neck

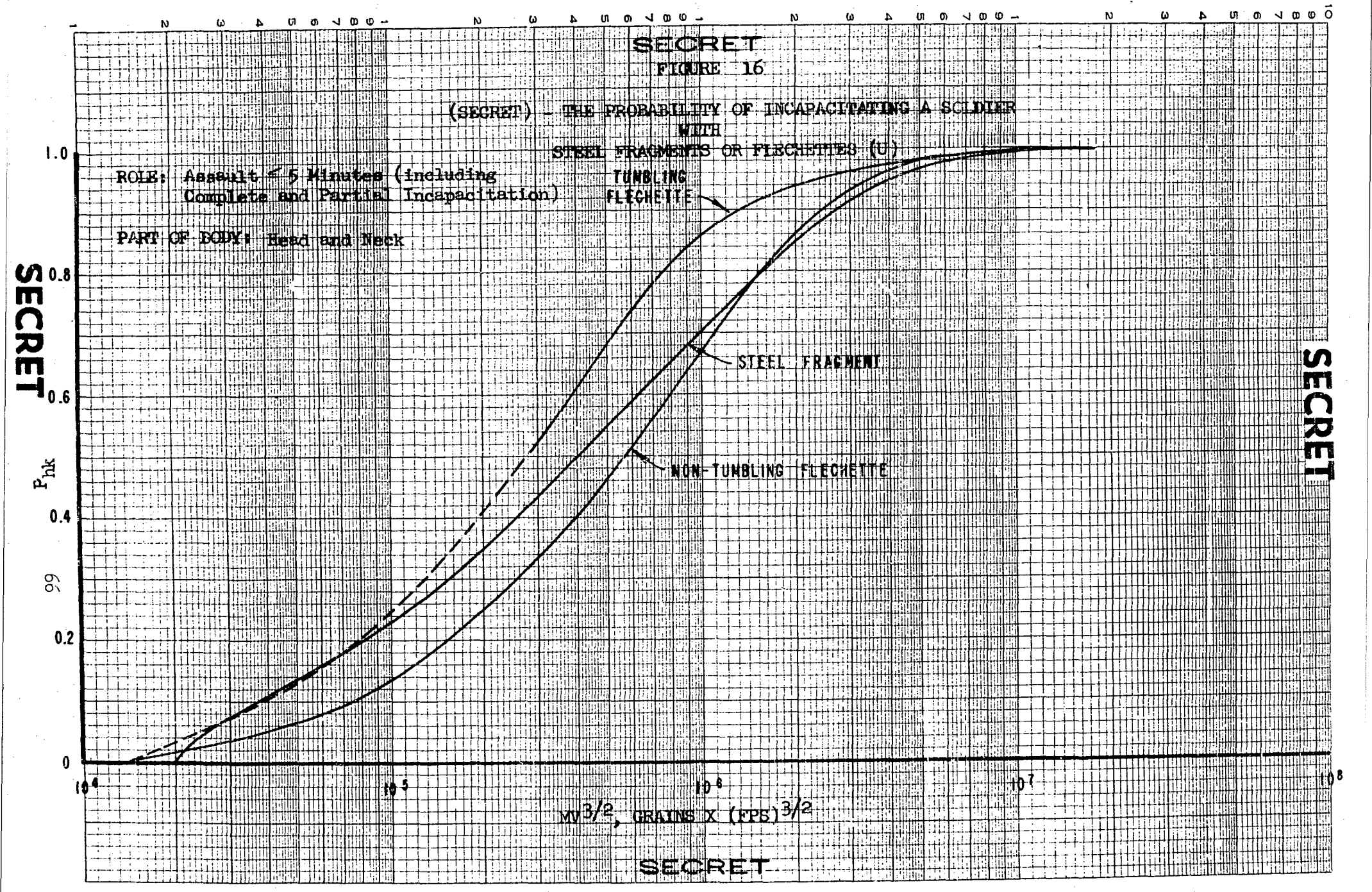

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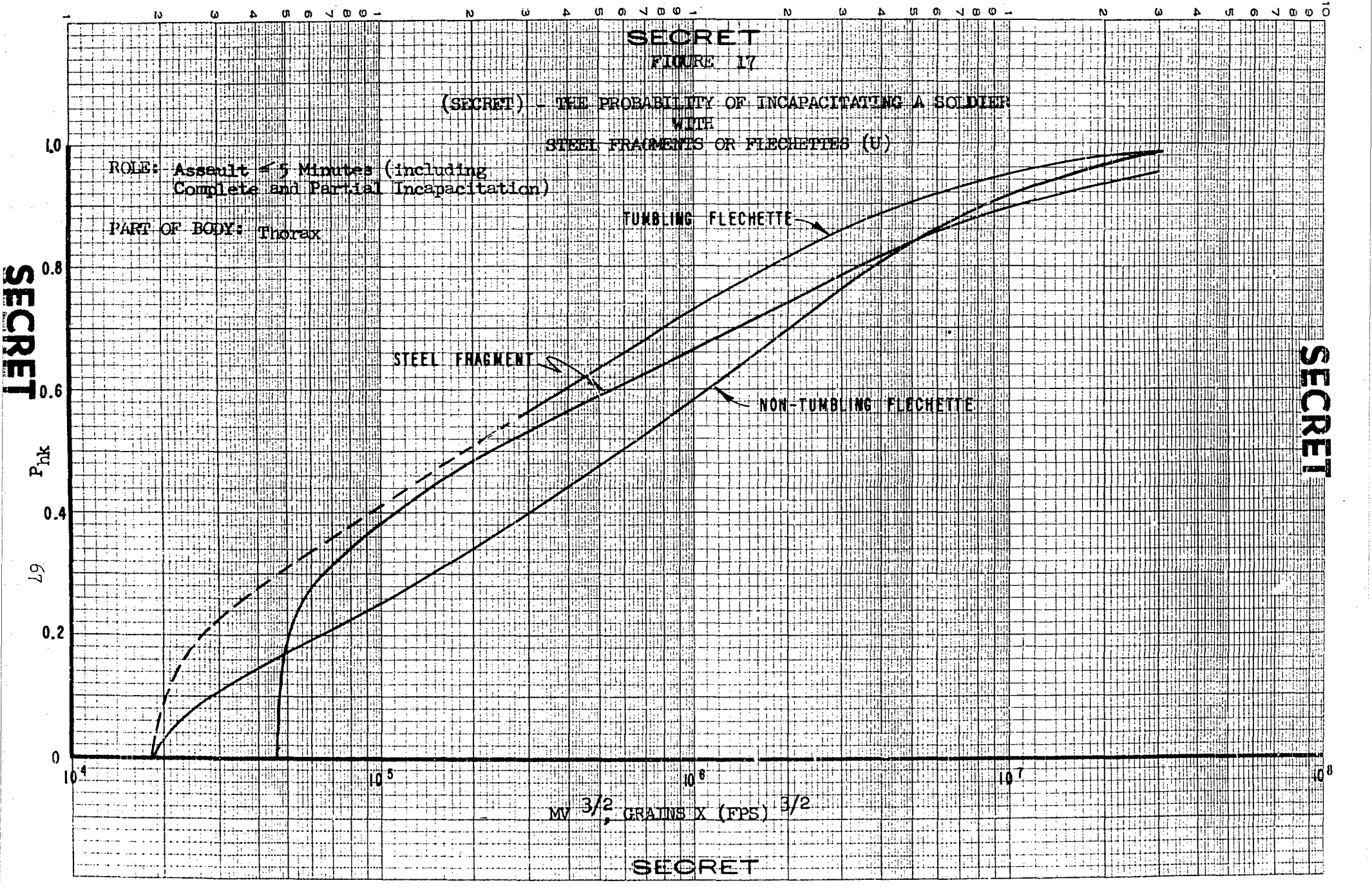
FIGURE 17

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)



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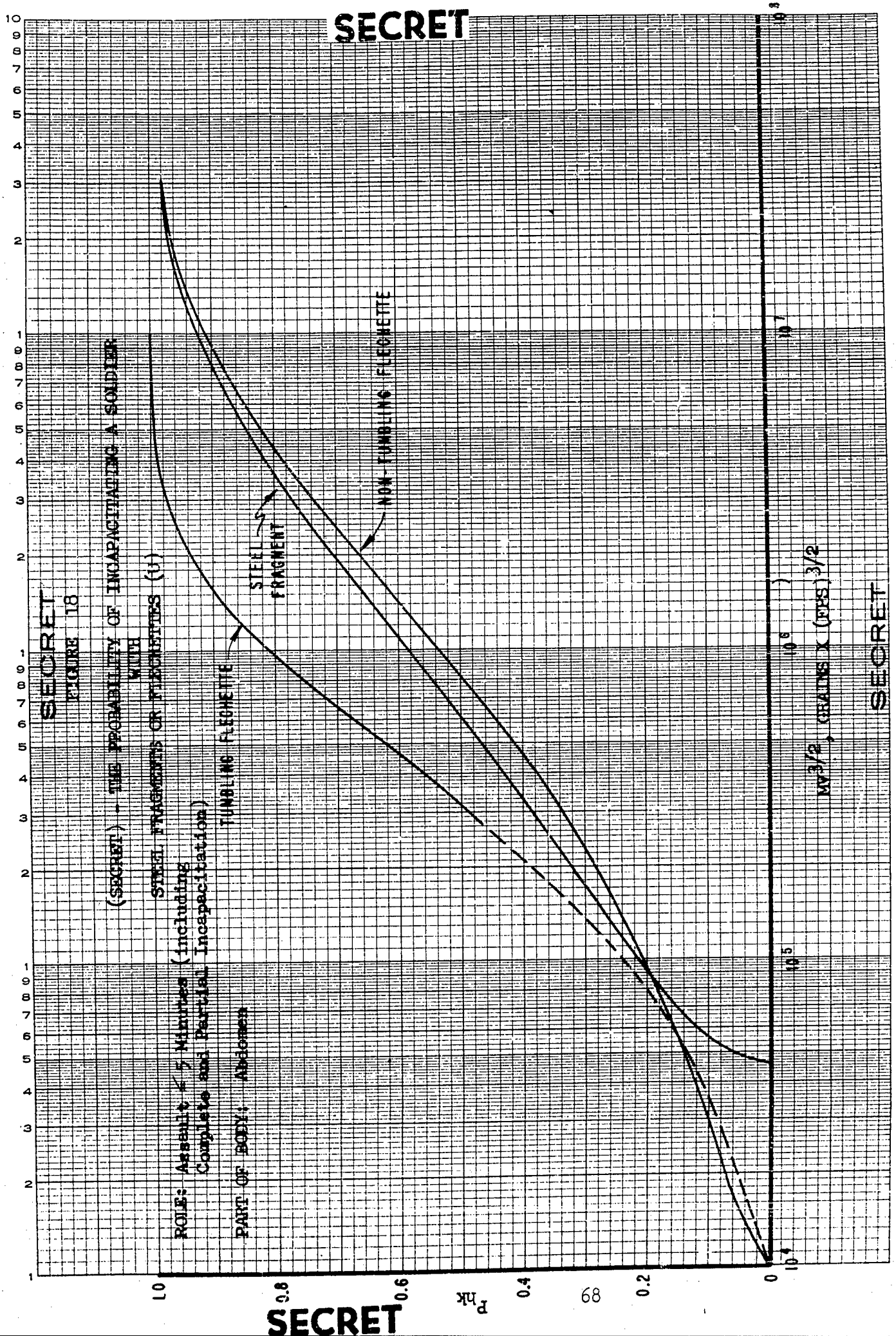

FIGURE 18

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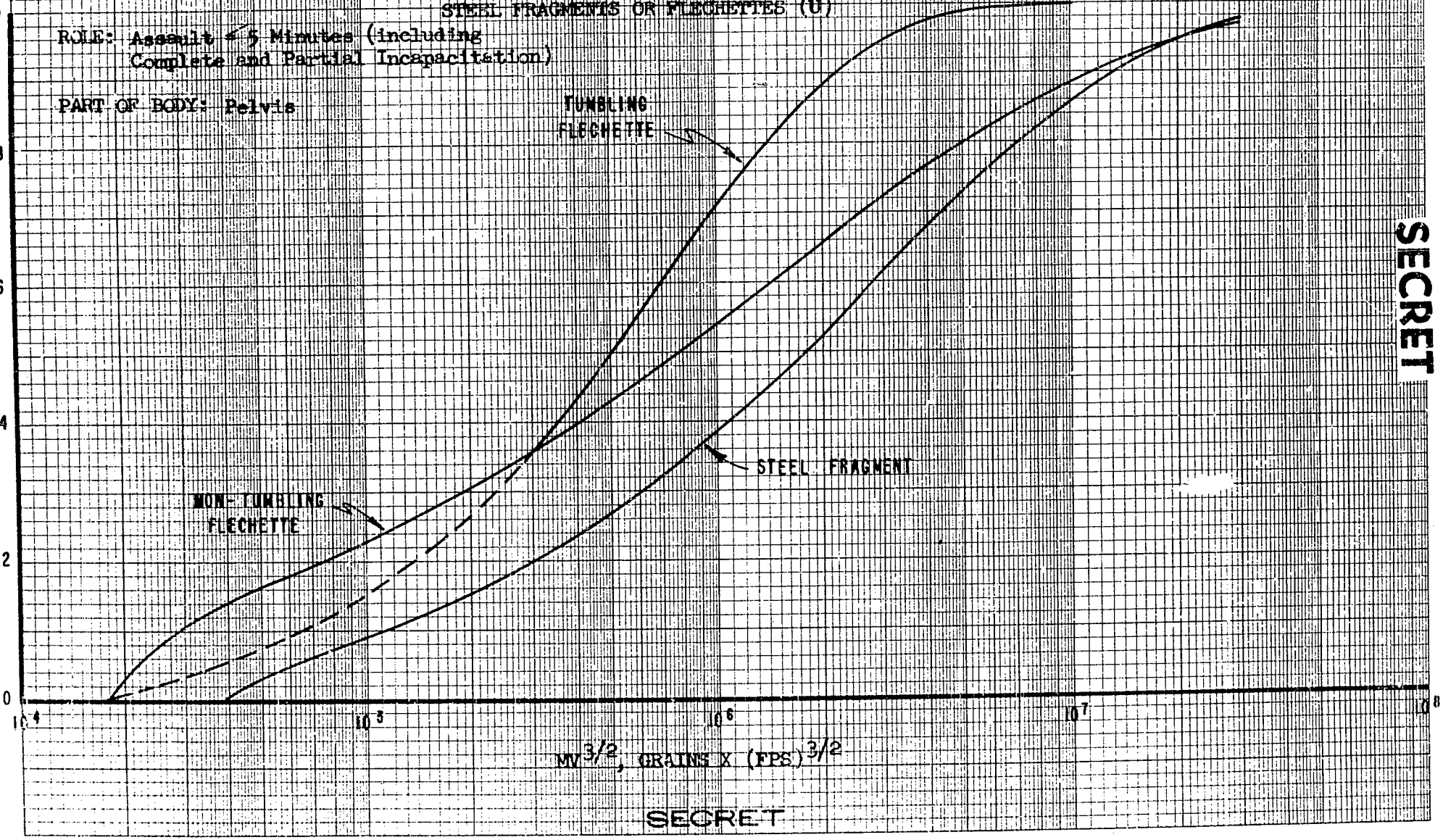
FIGURE 19

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault - 5 Minutes (including Complete and Partial Incapacitation)

PART OF BODY: Pelvis



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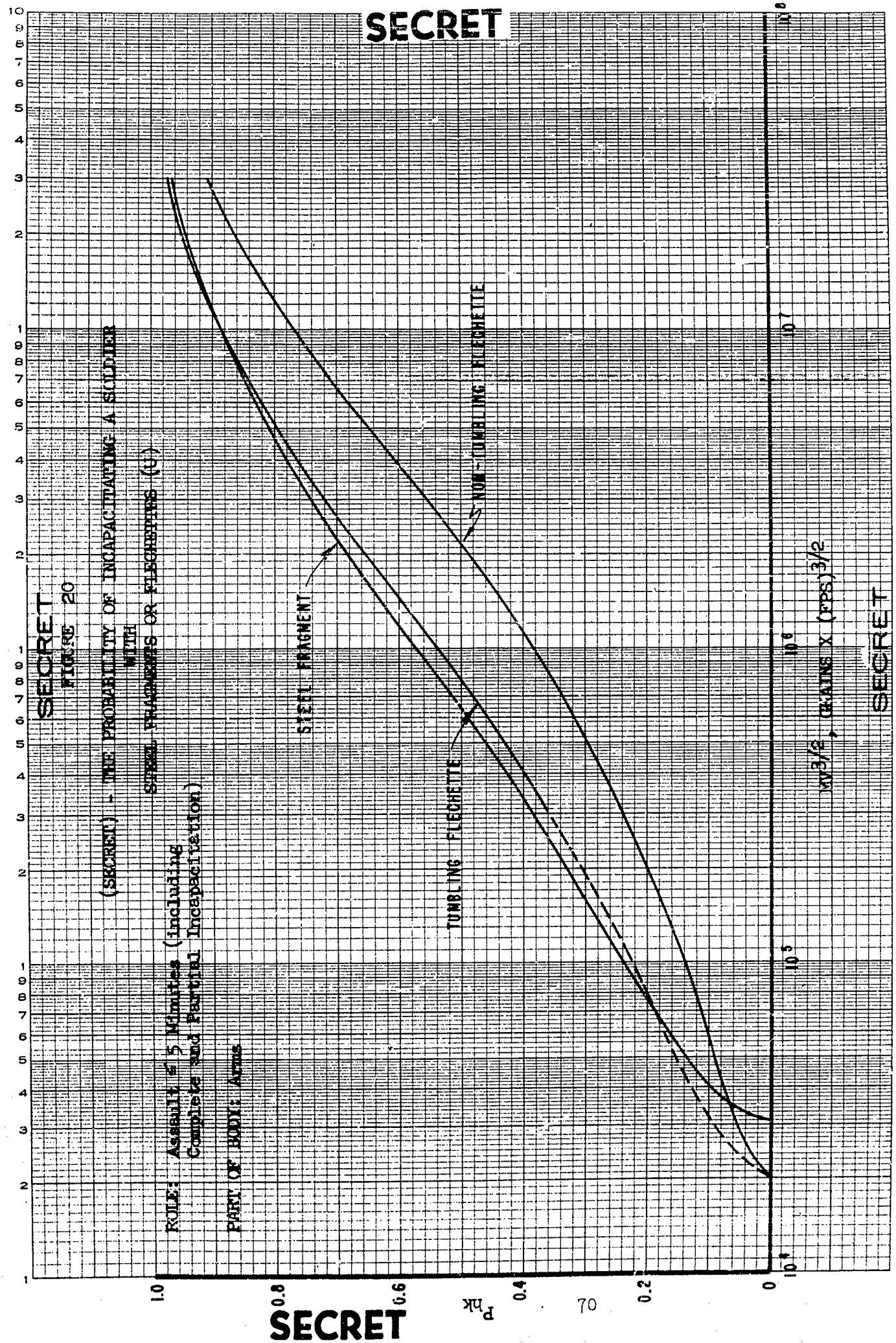
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FIGURE 20
(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)
RULE: Assault ≤ 5 Minutes (including Complete and Partial Incapacitation)
PART OF BODY: Arms
STEEL FRAGMENT
NON-TUMBLING FLECHETTE
TUMBLING FLECHETTE
P_{hk}
$W^{3/2}$, GRAINS X (FPS)$^{3/2}$
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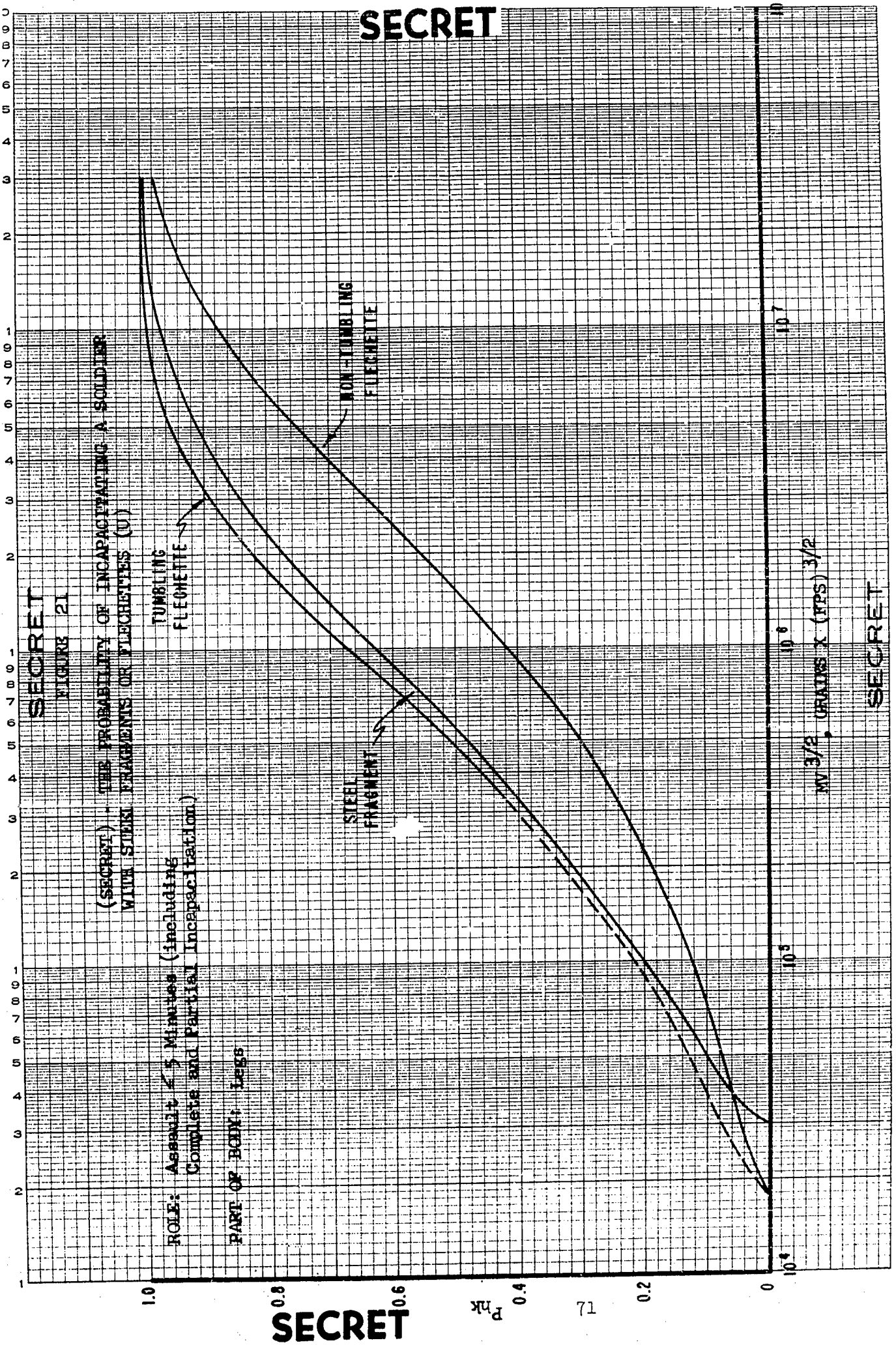
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FIGURE 21
(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)
ROLE: Assault ≤ 5 Minutes (including Complete and Partial Incapacitation)
PART OF BODY: Legs
TUMBLING FLECHETTE
NON-TUMBLING FLECHETTE
STEEL FRAGMENT
P_{hk}
1.0
0.8
0.6
0.4
0.2
0
10^8
10^7
10^6
10^5
10^4
$MV^{3/2}$, (GRAINS $\times$ (FPS)$^{3/2}$
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FIGURE 22

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense ≤ 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Entire Body

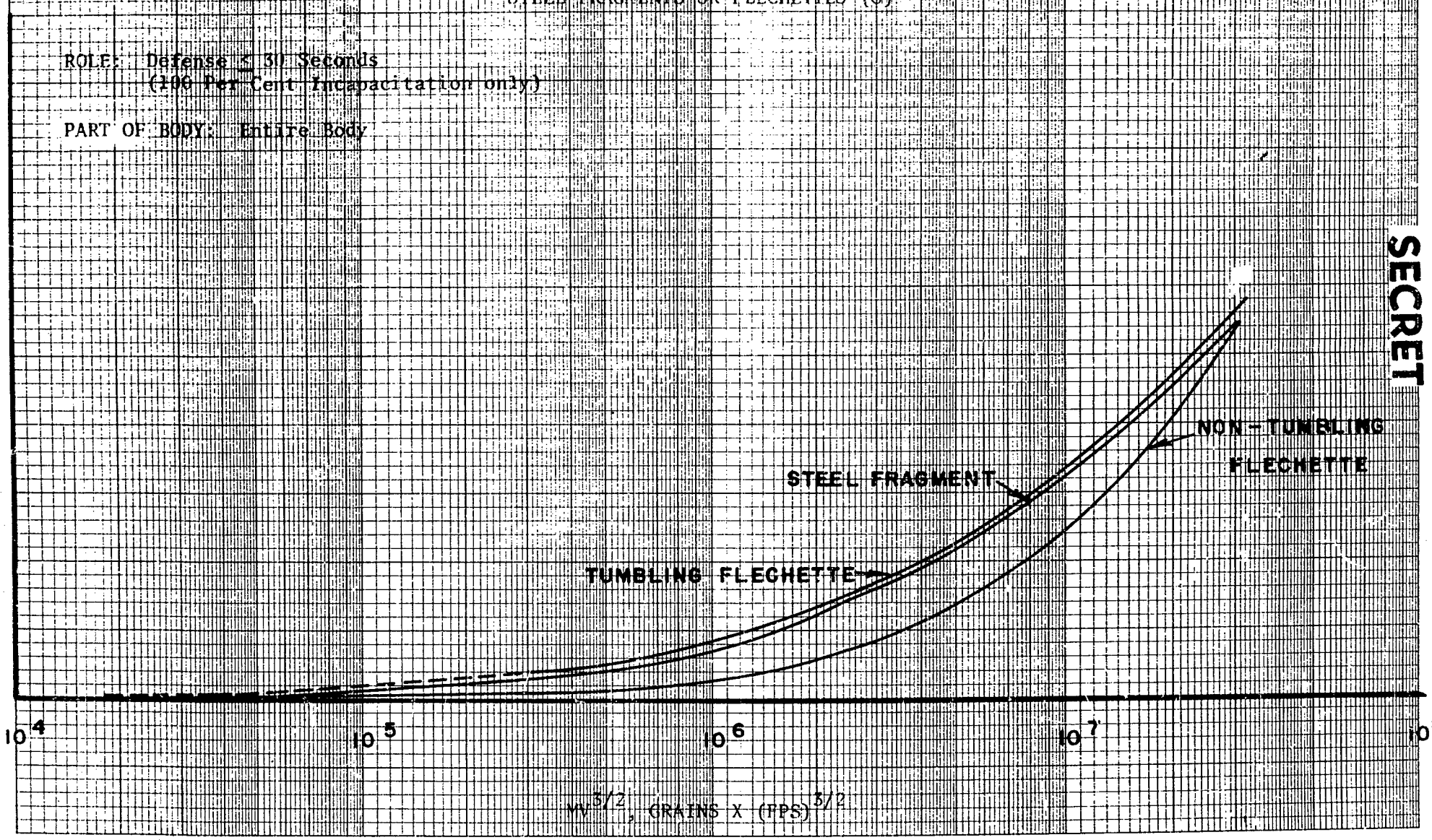

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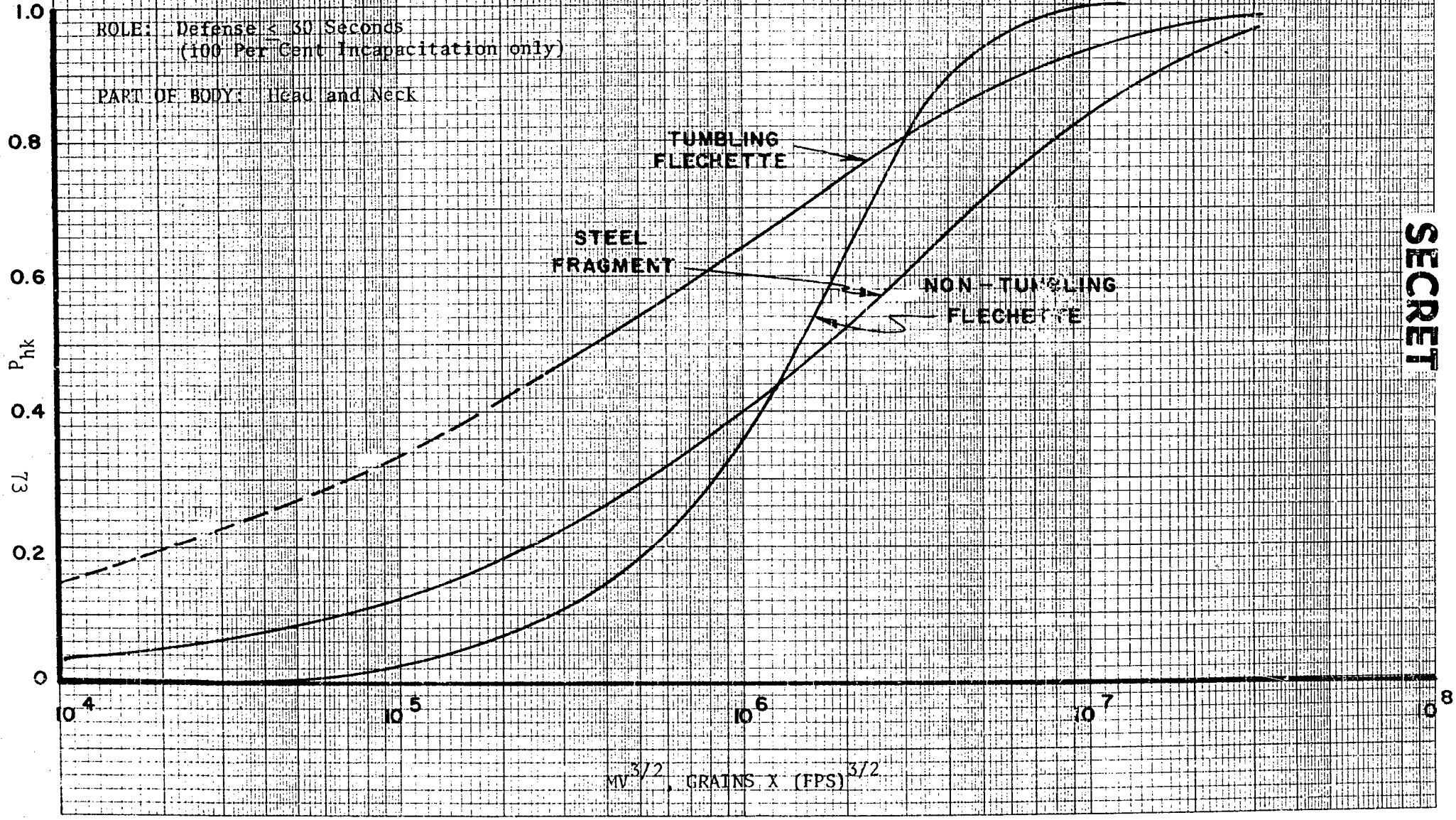
FIGURE 23

(SECRET) – THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)



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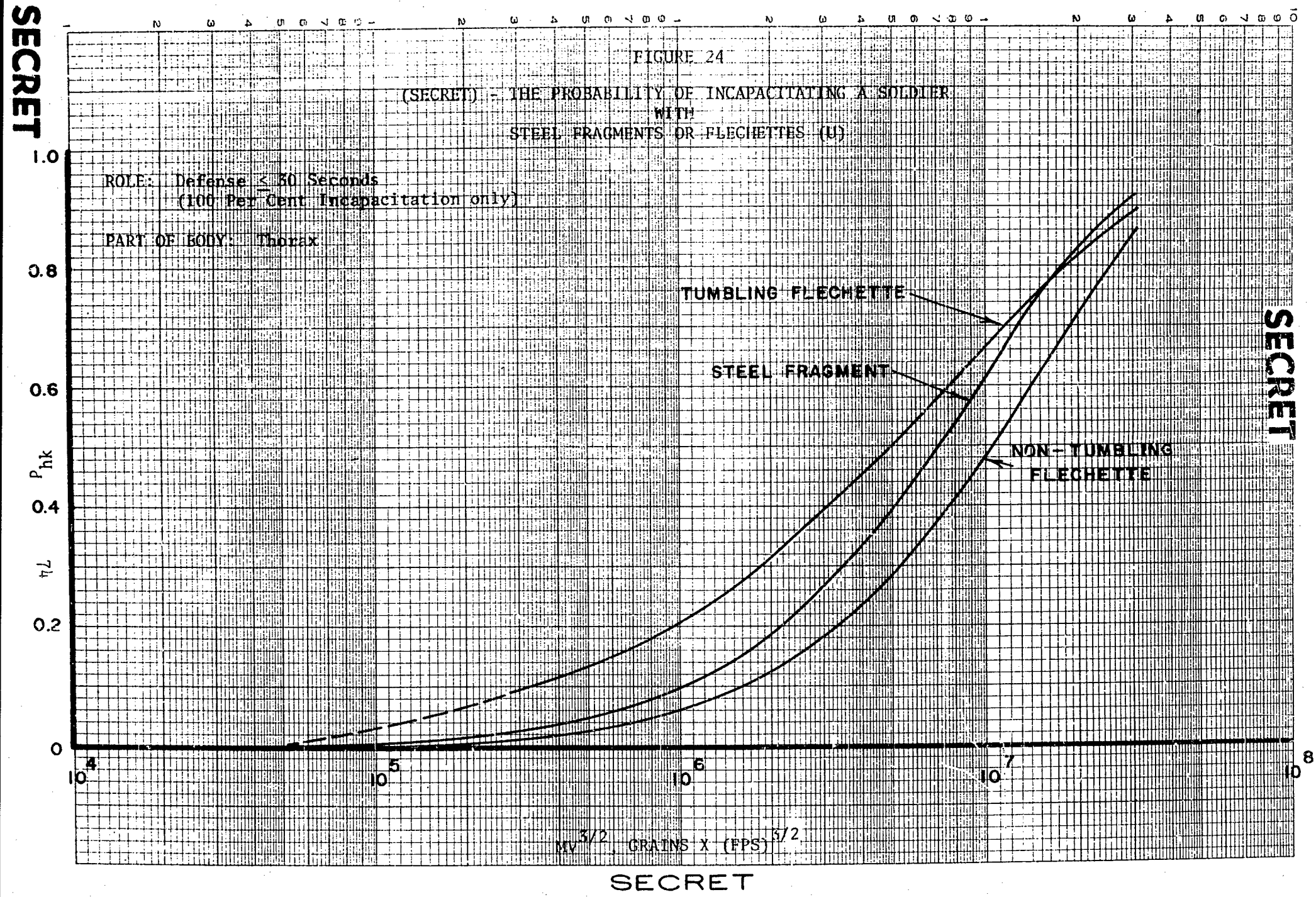
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FIGURE 24
(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)
ROLE: Defense ≤ 30 Seconds
(100 Per Cent Incapacitation only)
PART OF BODY: Thorax
TUMBLING FLECHETTE
STEEL FRAGMENT
NON-TUMBLING FLECHETTE
P_{hk}
1.0
0.8
0.6
0.4
0.2
0
10^4
10^5
10^6
10^7
10^8
$MV^{3/2}$, GRAINS X $(FPS)^{3/2}$
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FIGURE 25

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Abdomen

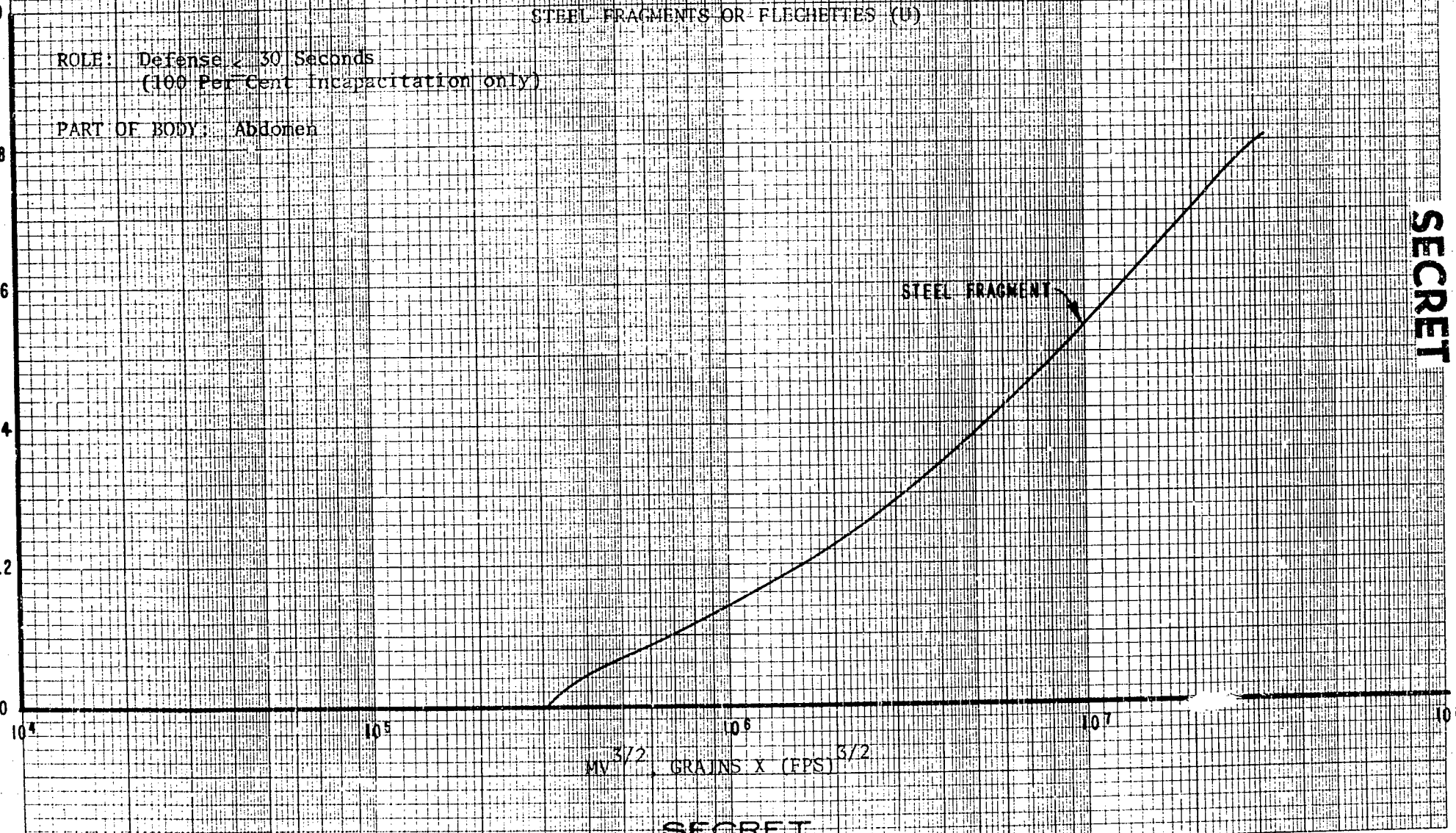

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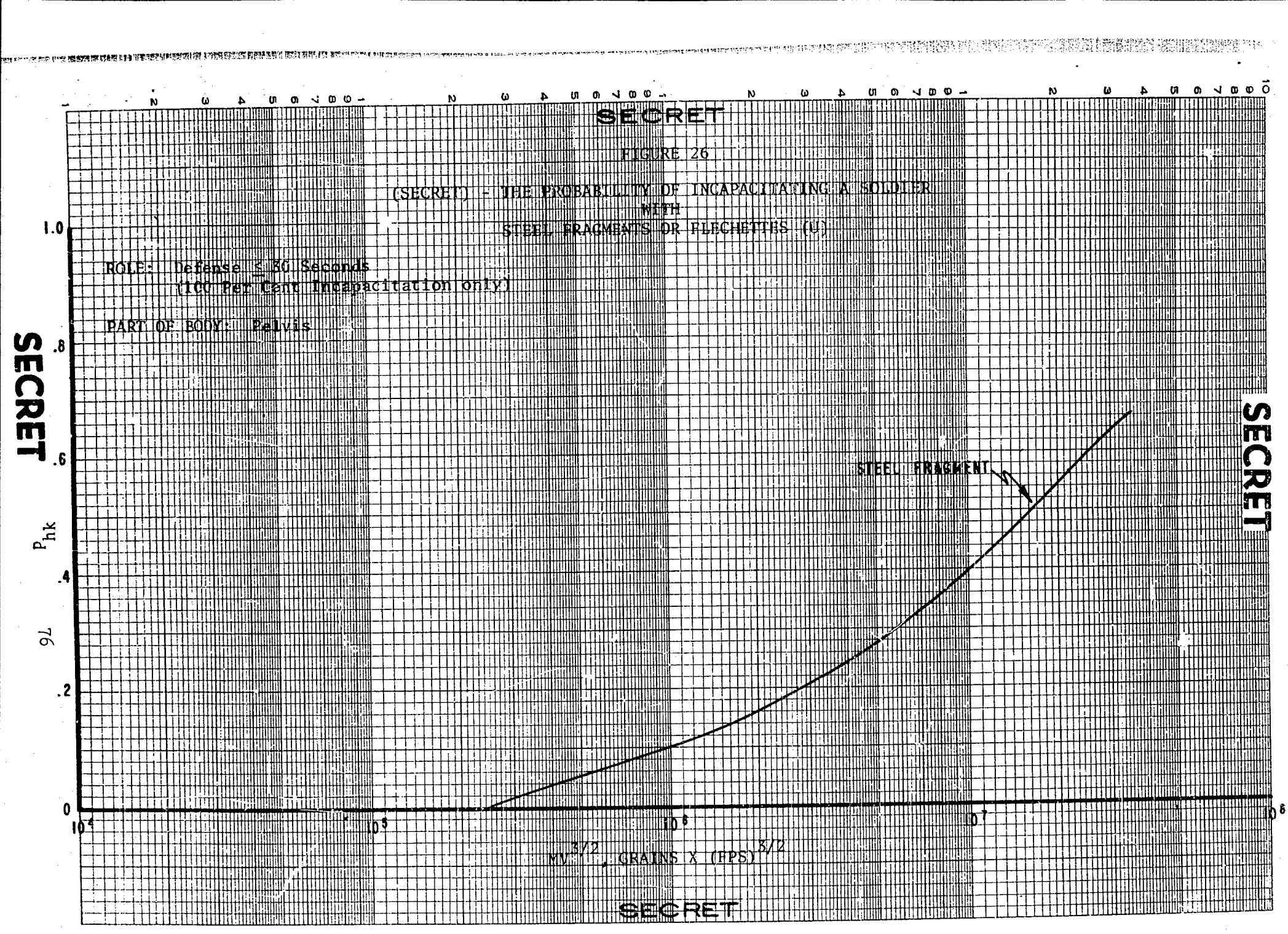
FIGURE 26

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense ≤ 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Pelvis



SECRET

FIGURE 27

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense ≤ 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Arms

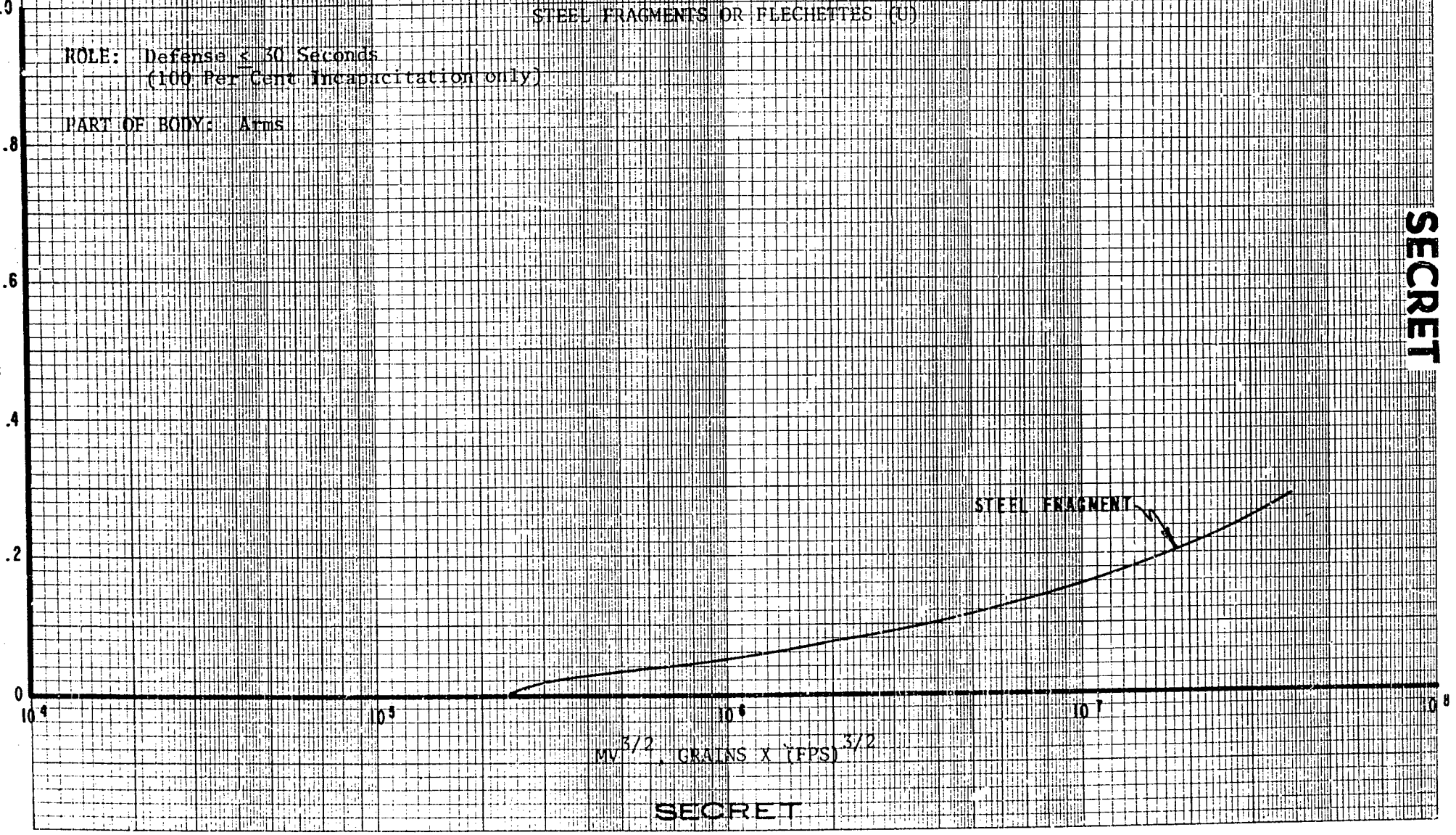


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FIGURE 28

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Legs

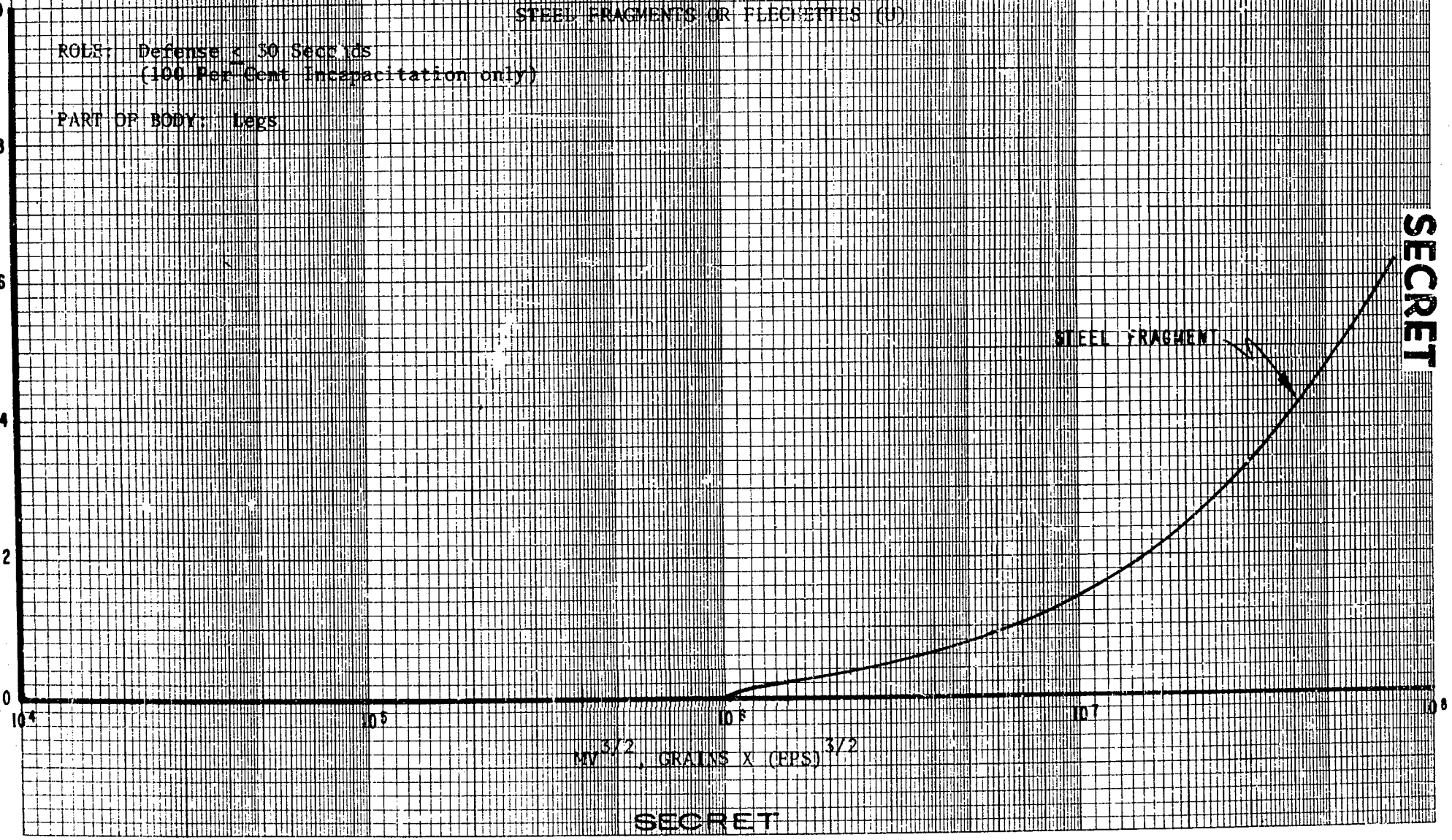

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FIGURE 29

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Assault - 30 Seconds
(100 Per Cent Incapacitation only)
PART OF BODY: Entire (Clothed)

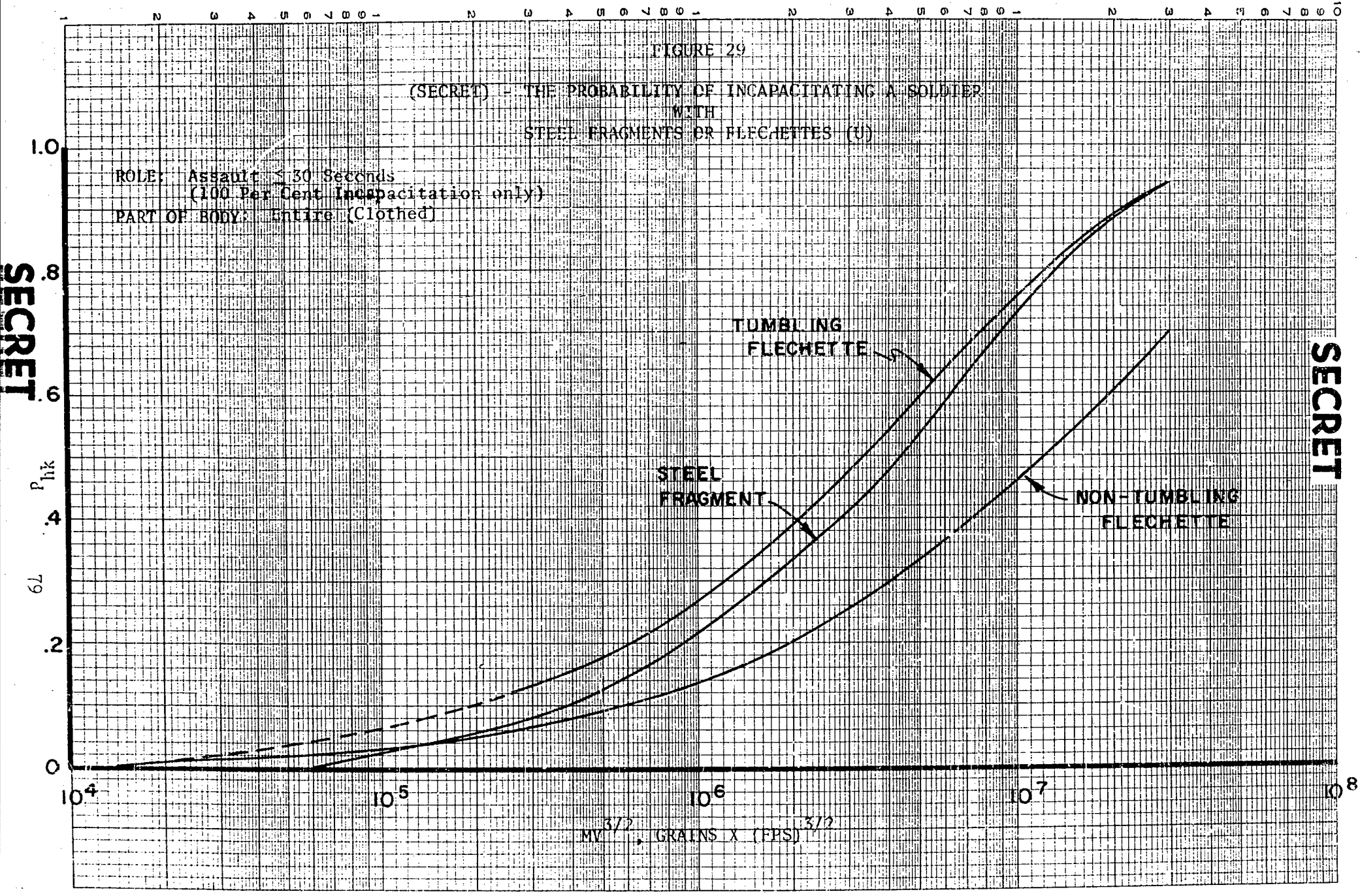

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FIGURE 30

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)

ROLE: Defense < 30 Seconds
(100 Per Cent Incapacitation only)

PART OF BODY: Entire

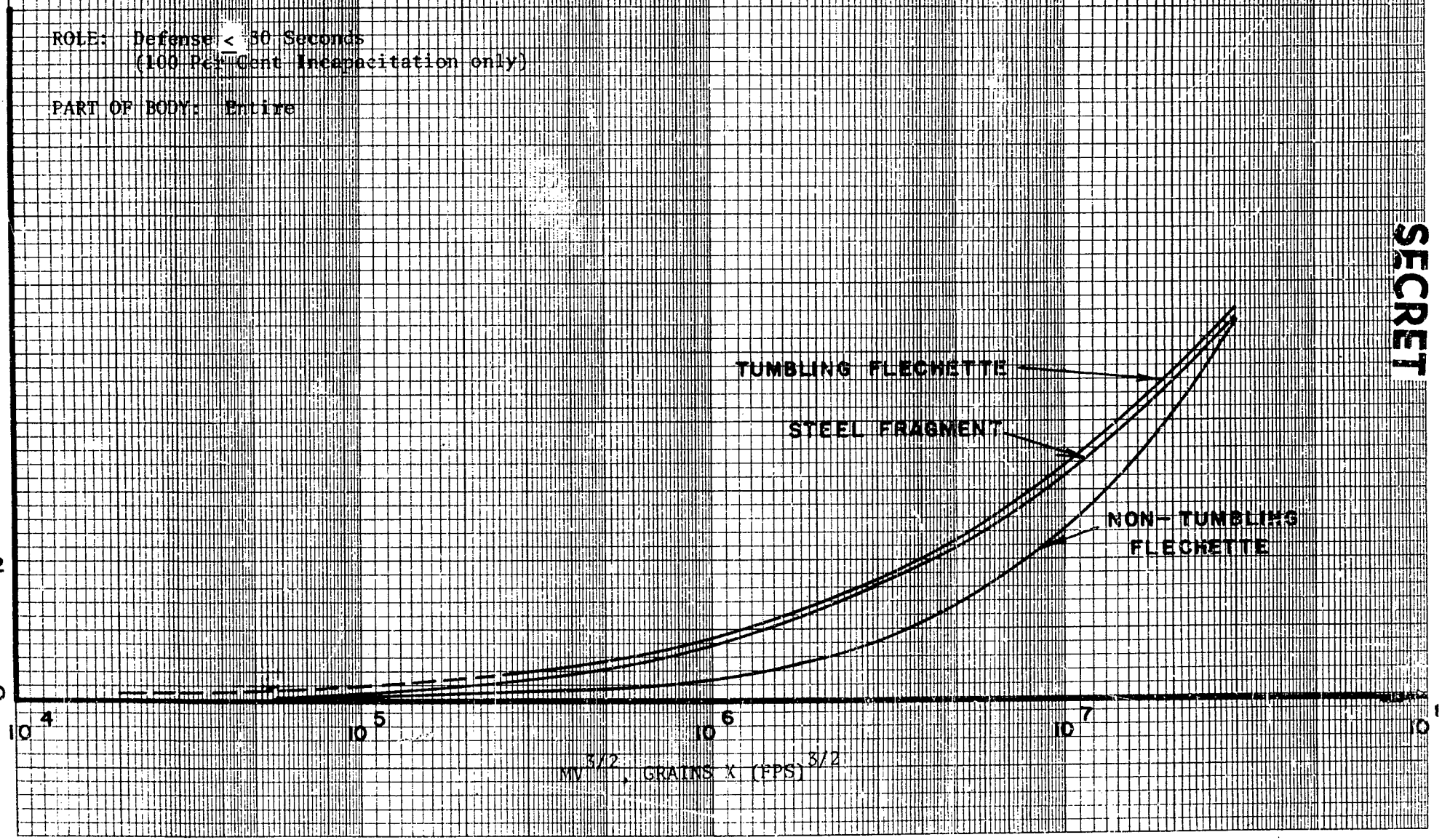
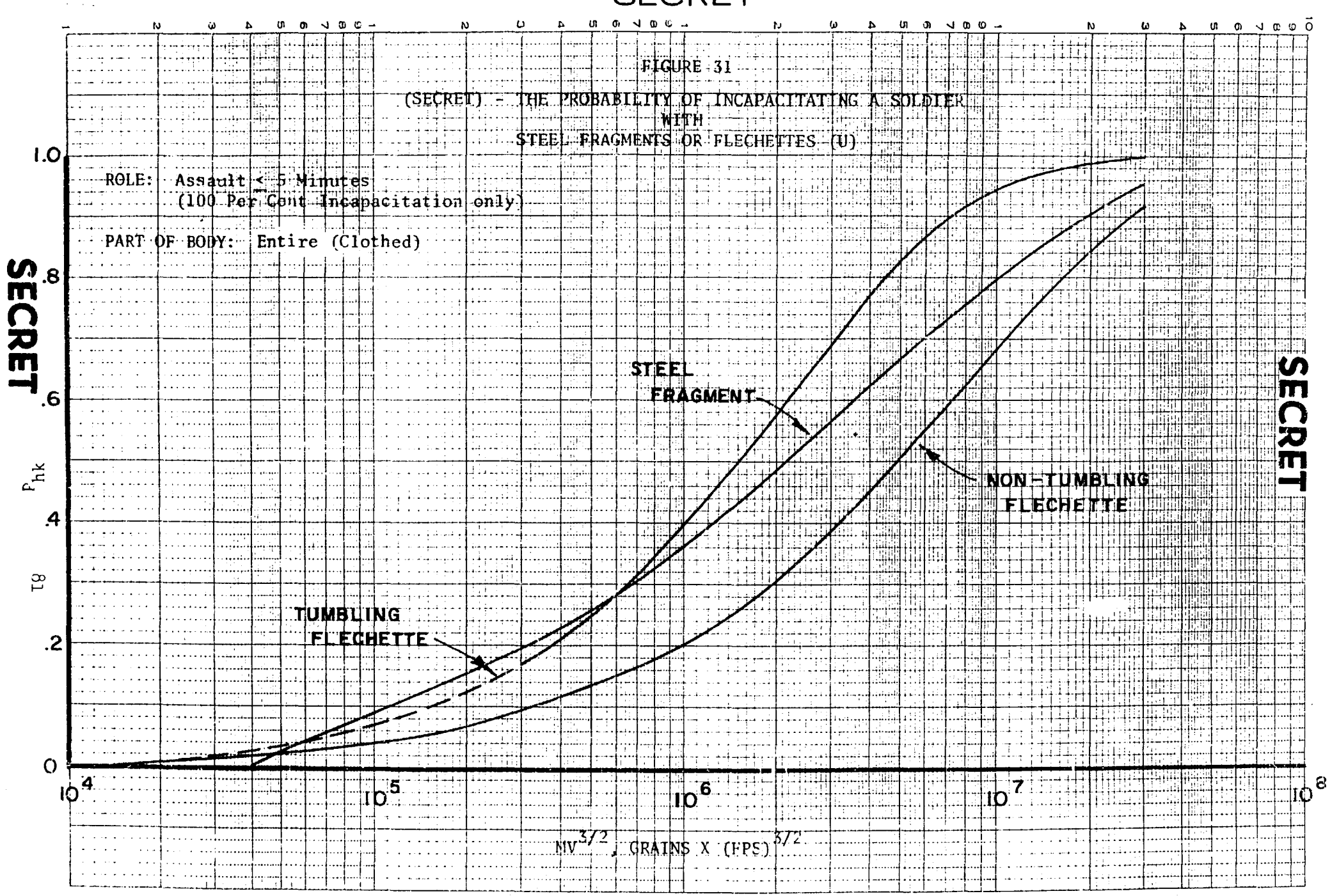


FIGURE 31

(SECRET) - THE PROBABILITY OF INCAPACITATING A SOLDIER WITH STEEL FRAGMENTS OR FLECHETTES (U)



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13. ABSTRACT

Presented are estimates of the conditional probabilities, P_{hk} that random hits with a standard series of homologously shaped, steel flechettes, will incapacitate the soldier. The functional dependence of P_{hk} on the weight, m, and initial striking velocity, v_o, of the flechette is given by an expression involving m, v_o and parameters a, b and n, whose values are determined from the tactical situation and time at which incapacitation is to ensue. Also presented are estimates, P_{hk} for chunky steel fragments. Although these latter criteria appear in other BRL publications, they are included for purposes of consolidation. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Flechettes						
Incapacitations						
Criteria						
P_{hk}						
Wounding						
Wound Tracts						
Tactical Roles						
Disability						